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THESIS

REFRACTIVE CONDITIONS IN ARABIAN SEA
AND THEIR EFFECTS ON
ESM AND AIRBORNE RADAR
OPERATIONS

by

Kamran Khan

September, 1990

Thesis Advisor:	Kenneth. L. Davidson
Co-Advisor :	CDR James R. Powell USN

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This thesis examines how atmospheric conditions influence the performance of radar and Electronic Warfare systems. Of particular interest is the frequency of occurrence of various types of ducts in the Arabian Sea which is presented. Potential tactical advantage through better knowledge of ducting conditions is also examoned. EREPS and IREPS, PC based programs for evaluating the atmospheric effects on radio systems, are addressed. An application of the above is the Airborne Microwave Refractometer (AMR) installed in an aircraft which samples the above conditions and provide an assessment of the meteorological profile of the atmosphere. The proposed installation in Pakistan Navy P-3C is discussed.

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Refractive Conditions in Arabian Sea and their effects on ESM and Airborne Radar Operations

by

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Lieutenant Commander, Pakistan Navy
B.S.E, Pakistan Naval Academy

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING(ELECTRONIC WARFARE)

from the

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ABSTRACT

This thesis examines how atmosphere influence the radar and Electronic Warfare systems. Of particular interest is the frequency of occurrence of various types of ducts in the Arabian Sea which is presented. Potential tactical advantage through knowledge of ducting conditions is also examined. EREPS and IREPS, PC based software systems for evaluating the atmospheric effects on radio systems, are addressed. An application of the above is the Airborne Microwave Refractometer (AMR) installed in an aircraft which samples the above conditions and provide an assessment of the meteorological profile of the atmosphere. The proposed installation in the Pakistan Navy P-3C aircraft is discussed.

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TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The proper tactical use of modern naval warfare and weapon sensor systems can be dramatically affected by the atmospheric effects on the propagation of electromagnetic waves. Refractive conditions of the atmosphere, particularly over the sea, should play an important role in the way we use our sensors. An early potential issue in the destruction of Iran Airbus A300 on 3 July, 1989 was the possible misinterpretation of information given by USS VINCENNE's air search radar system. The anomalous atmospheric conditions could have distorted the height information that led to the belief that the aircraft was descending as opposed to climbing.

Unusual atmospheric propagation effects have been observed since the invention of radar. The effects of the atmosphere on Electromagnetic (EM) waves have been affecting the use of surveillance, weapon guidance, communications, and EW systems since before World War II. Submarines in WW-II observed that their radars were performing unpredictably. Aviators received signals from transmitters supposedly too distant for reception. On the other hand there were reports of some transmissions that were not reaching as far as expected. Kerr

[Ref. 1:p. 371] quotes a famous example of WW-II sighting of Arabia with a 200 mhz radar from Bombay, India, 1700 Miles away. Somewhat similar performance was noted on a radar site at Karachi. Propagation conditions also can negatively affect the radar ranges. Instances have been reported when for periods of several hours, radar on Fisher's Island, New York, could not pick up Black Island 22 miles away although it was optically visible. Many past observed propagation anomalies were encountered over the oceans, where atmospheric ducting is more significant and consistent than over land. For example, evaporative ducting, to be described, is a persistent phenomenon found only over water.

It has long been recognized that the changing distributions of temperature and humidity in the lower atmosphere can produce significant changes in radio wave propagation. Such anomalous propagation may cause enhancement or degradation of naval surveillance, communication and EW systems. Therefore, besides reliable prediction of severe sea and weather conditions, the environmental factors which enhance or degrade a wide range of weapon and sensor systems using electromagnetic waves also must be considered.

Microwave signal propagation at low altitude over the ocean is quiet different from normal line of sight propagation. Due to presence of a certain vertical gradient of temperature and humidity a microwave ducting phenomena occurs near the ocean surface. The refractive layer causes

electromagnetic energy to bend towards the earth at a rate equal or greater than the earth's curvature. Signals travelling in the duct tend to follow the curvature of the earth and attenuate slowly, which allows Over The Horizon (OTH) detection. In addition to increased ranges it also causes gaps or holes in the normal coverage of the radar.

The abnormal (anomalous) propagation of radio and radar waves is referred to as subrefraction, super-refraction, and trapping. These will be discussed in more detail later. The duct arises from trapping and is probably the most anomalous region in the lower atmosphere. Formation of a duct occurs when a mass of warm, dry air covers a layer of sufficiently cool, moist air. This situation results in a temperature inversion and an abrupt change in humidity that causes a discontinuity in the index of refraction of the atmosphere. This refractive structure establishes the trapping condition. Thus, electromagnetic waves may be trapped by an elevated duct and guided over long ranges with low loss. Ducting can occur over land but is more prevalent over the sea.

Tactical advantage can be established by employing knowledge of duct locations. Prediction of a surface based duct suggest probable extended ranges for transmitter receiver antenna pairs in the duct and possible holes or gaps in coverage just above the duct that can be exploited to own advantage. The advantage includes being able to make realistic estimate of ESM detection and counter detection ranges. This

would enable the OTC to make decisions concerning emission control (EMCON), the positioning of both air and surface surveillance assets, the altitude and flight profiles for strike aircraft to minimize detection, placement of EW jammers for maximum effectiveness and many other tactical considerations.

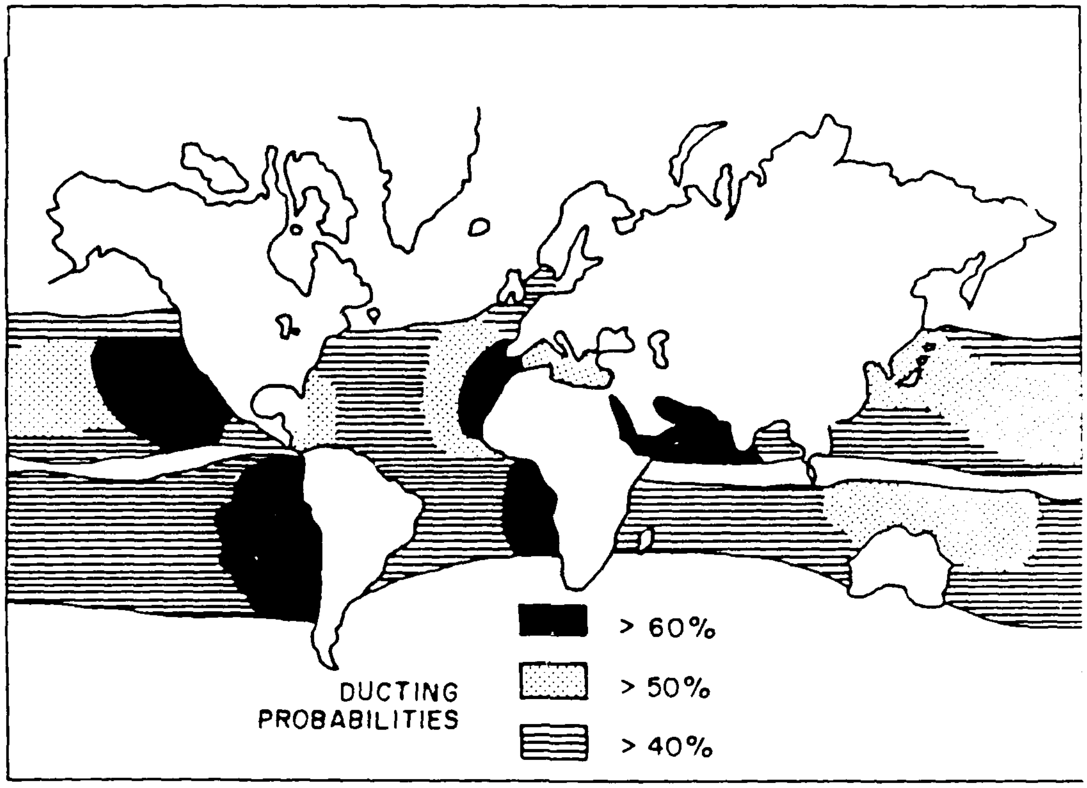


Figure 1 Global frequency of duct occurrence

The Arabian Sea, one of the most important operational areas in the world, lies within the belt around the equator (trade wind region) where ducts occur quite frequently. The occurrence is increased due to the adjacent land masses. The study of prevalent weather conditions in the area with a short term forecast of changes can enable the tactical commander to

foresee how the weather conditions can influence his EMCON plan in that area or along a certain given track. Knowledge of predicted ESM ranges against predefined sets of radars and assessment of maximum expected intercept range of own emitters is essential. Positioning of the AEW platform and other receiver platform to achieve maximum tactical advantage is of paramount importance.

A refractometer is being used onboard US Navy E-2C aircraft for assessing propagation conditions. The airborne refractometer provides an assessment of the meteorological profile of the atmosphere, both in real time and recorded (continuous throughout the flight duration). More specifically it identifies and locates, with respect to altitude, these refractive layers (caused by moisture and temperature discontinuities) that are known to have an impact on communications and surveillance. The information available from an ESM receiver and from the onboard refractometer can greatly enhance the mission effectiveness of an Airborne Early Warning (AEW) aircraft. The Pakistan Navy is acquiring P-3C aircraft from the United States. Integration and proposed installation of a refractometer onboard will be discussed.

B. OBJECTIVES

Objectives of the thesis are to:

1. Discuss basic parameters and profiles used to describe refractive effects.

2. Discuss the general refractive conditions prevalent in the Arabian Sea.
3. Examine the effects of refractive conditions on radar waves and ESM operations using Engineers Refractive Effects prediction System (EREPS) and Integrated Refractive Effects Prediction System (IREPS).
4. Examine the value of using an Airborne Microwave Refractometer (AMR) in the given refractive conditions and its possible installation on Pakistan Navy P-3C aircraft.

II. FUNDAMENTALS OF EM WAVE PROPAGATION

A. RADIO WAVE PROPAGATION

Electromagnetic radiation is energy that travels in the form of waves. All the waves travel at the same speed in vacuum, but differ in wavelength and thus frequency. They comprise the whole EM spectrum that is a continuous spectrum with no actual limits on either the upper or lower ends of the wavelength or frequency scale. Generally electromagnetic spectrum is described according to the methods used to detect and produce waves of differing wavelengths and is often separated into Electro Magnetic (EM) and Electro Optic (EO) portions. The electromagnetic portion extends wavelengths of one centimeter (microwave) to longer wavelengths. The optical portion corresponds to wave lengths from 0.4 to 100 micrometers, and ranges from visible through infrared (IR).

Eaves [Ref. 2:p. 51] describes how the propagation of electromagnetic radiation depends on the conditions existing within the atmosphere through which the radiation must pass. Some of the mechanism that influence the propagation of the radio waves are:

1. Reflection or scattering from the earth's surface
2. Diffraction due to earth's curvature
3. Ionospheric reflection

4. Atmospheric refraction

Propagation of EM/EO waves also can be subjected to molecular absorption, extinction, wave front distortion, scattering by precipitation, diffraction by hills and mountains, polarization rotation and pulse dispersion. Atmospheric factors contributing to these effects are the vertical gradients of temperature and humidity for refraction, small scale inhomogeneities (turbulence) of the index of refraction for optical wavefront distortion, concentration of water vapors and aerosols for extinction (absorption and scattering) and turbulent transport for dispersion. Above factors are dependent on routinely measured and predicted meteorological variables; pressure, wind, temperature, and moisture. The effects of these variables are predominant on the shorter wavelengths, from about 1 cm to 10 cm. At wavelengths shorter than 1 cm, the atmosphere becomes somewhat opaque due to greater absorption that makes long distance propagation impractical.

For propagation studies the atmosphere can be roughly divided into two layers, the troposphere, and the ionosphere. The properties of the troposphere changes with altitude and weather conditions that contribute toward bending of EM waves. The ionosphere reflects signals that are in the HF range and lower. The degree to which the atmosphere affects the EM wave depends on the frequency of transmission. Besides frequency considerations, radio waves can also be classified according

to the path they take from the transmitter to the receiver. This includes ground or surface waves, sky waves, space waves, and scattered waves.

The interference and diffraction regions are the two re‿.ons of influence where the earth and its atmosphere affects the antenna pattern. The interference region is the portion of space that is illuminated by both a direct ray from the transmitter and a reflected ray from the earth's surface. This causes the multipath interference effect. The diffraction region is the region of space below the horizon in which the existence of a received field cannot be explained in terms of energy travelling in straight line from transmitter. The radio waves must somehow be bent to arrive in the diffraction region of space. The mechanism by which radio waves curve around edges and penetrate the shadow region behind an opaque obstacle is called diffraction. Low frequency radars are more effective in detecting targets behind mountains than high frequency ones.

B. TROPOSPHERIC REFRACTION

Refraction is important in the troposphere. It describes the capability of the atmosphere to bend an EM ray. Refraction is the change in the direction of travel of radio waves due to spatial (along the wave front) changes in the index of refraction. The index of refraction **n** is:

$$n = c/v \tag{1}$$

where c is the speed of light in a vacuum and v is the wave phase velocity in the medium. A variation in the index of refraction causes the EM waves to bend toward the region of higher index of refraction. The index of refraction of the atmosphere normally decreases with increasing height. At greater heights the less dense atmosphere results in a smaller index of refraction. The above relation shows that v increases as n decreases, therefore the portion of the transmitted wave at higher altitudes travels faster than the part that is closer to the ground. This causes the ray to curve or bend downward in accordance with the Snell's Law of refraction.

The effects of refraction can be understood by assuming the atmosphere to be divided into a series of planer slabs or layers, each having a constant index of refraction, and that the earth is approximated by a plane. From Snell's Law

$$n_o \sin\theta_o = n_1 \sin\theta_1 = n_2 \sin\theta_2 = \ldots\ldots\ldots = n_i \sin\theta_i \tag{2}$$

where n_i is the index of refraction of the ith slab. Thus if n_i (i=0,1,2,3.........) and the angle at which the wave is transmitted are known, the angles can then be calculated using above relationship. This is how the path of the ray is determined.

A better approximation can be obtained by using the earth as spherical, instead of planer surface, and further by assuming that the electrical properties of the atmosphere are

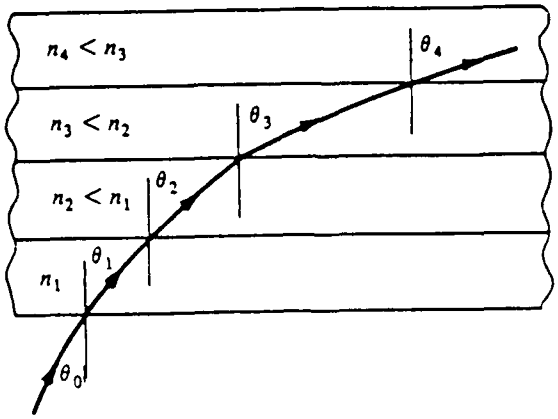


Figure 2   Illustration of Ray Curvature.

constant between concentric spheres. The usual effect of refraction is to cause the measured ranges and elevation angles to be larger than the true values. The range measurement is exceeded due to the longer time of travel.

Skolnic [Ref. 3:p. 449] describes how the effect of ray curvature can be taken into account in a simple way for propagation over a spherical earth by replacing the earth with an earth having a larger radius and considering the rays to propagate along straight lines, provided index of refraction decreases linearly with height. In a most general way the actual earth radius, a (a=3440 Nautical Miles), is replaced by an effective earth radius, a_e, and actual atmosphere is replaced by a homogeneous atmosphere where EM waves travel in straight lines rather than curved lines. Therefore a standard index of refraction profile is commonly chosen such that it is

equivalent to increasing the radius of earth by a factor k = 4/3. Thus the effective earth radius, a_e, is chosen to be 5280 NM. This gives us an accurate determination of 'distance' above horizon for a standard atmosphere and allows us to draw the radar rays as straight lines on the earth.

The tropospheric index of refraction depends on temperature, humidity, and pressure. At microwave frequencies, the index of refraction, **n**, for air that contains water vapors is given by :

$$N=(n-1)*10^6=77.6*\frac{P}{T}+3.73*10^5*\frac{e}{T^2} \qquad \textbf{(3)}$$

where

P = Barometric pressure, mb

e = Water vapor pressure, mb

T = Absolute temperature, K

The parameter N = $(n-1)*10^6$ is obtained by scaling up the index of refraction and is called Refractivity. It is often used in propagation work instead of index of refraction, **n**, as it is a more convenient unit to work with. The barometric pressure and the water vapor pressure decreases rapidly with height, whereas the temperature decreases slowly with height. From Equation 3 it becomes evident that the index of refraction will decrease with increasing altitude. A value of **n** near the earth's surface varies from 1.000250 to 1.0004. The value of **N** thus varies between 250 to 400.

A better description of refractivity is not its value but its gradient dN/dh. Refractivity normally decreases with altitude at a rate of 0 to 79 N/km, known as normal gradient, which causes the ray path to bend downwards in space, but at a rate less than the earth's curvature. For a standard atmosphere **N** decreases with height at a rate of about 39 N/km. The previously discussed 4/3's earth (k=4/3) depiction is based on this **N** gradient.

It has been realized that the refractivity, **N**, is not very elaborate in depicting the refractive conditions because a normal situation is one in which it decreases with height. Therefore a most commonly used form of modified refractive index is one in which 157 N-units/km is added to all N-values. This modified refractive index, **M**, is defined as

$$M = N + 157*h$$

where **h** is height above earth in km and **N** is the refractivity at that height.

When the M-gradient is zero, the ray curvature equals the earth's curvature. Therefore when the N-gradient dN/dh = -157 units/km, the ray has the same curvature as that of earth. **M** will increase with height in the standard atmosphere, but may decrease or increase in non-standard atmospheric conditions.[Ref. 4:p. 4]

The modified refractivity, **M**, is very helpful in detecting the presence of trapping layers since trapping occurs for negative gradients of **M**. It takes into account the curvature

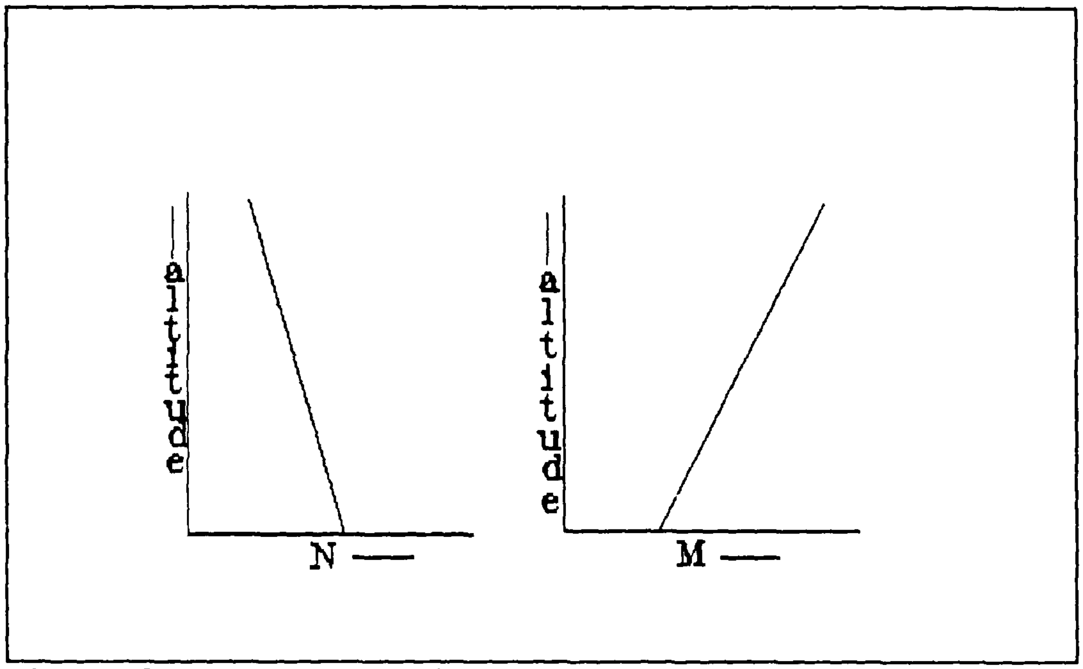


Figure 3 Refractivity N and Modified Refractivity M Profiles for Standard Atmosphere.

of earth so that the presence of ducting can be determined from a simple inspection of **M** plotted versus height. Whenever **M** decreases with height, a trapping layer is formed in which an EM wave can be refracted towards the earth's surface to form a duct.[Ref. 5:p. 83]

C. ANOMALOUS TROPOSPHERIC PROPAGATION

Refraction can cause an optical illusion, primarily where warm air can remain aloft over a somewhat cooler surface. However light comprises only a small portion of the spectrum and refraction can occur at other frequencies as well. Pre-world war II experiences of abnormally long distance VHF radio transmission reaching abnormally long distances can now be

understood in terms of refraction of the radio waves by elevated tropospheric layers. The index of refraction decreases with height and the radio wave is bent to extend the coverage beyond that is expected with a uniform atmosphere. Strong gradient of the index of refraction that causes the rays to have the same curvature as the earth itself, can extend radar ranges. Refraction is predominant at low angles of elevation, especially at or near the horizon. It can usually be neglected at angles greater then 3 to 5 degrees in most radar applications [Ref. 3:p. 450]. The form of deviation from standard refraction that commonly occurs in many parts of the world are subrefraction, super-refraction, and ducting (trapping) as shown in Table 1. The units are refractivity units per kilometer.

TABLE 1

CATEGORIES OF REFRACTIVITY

Standard	Subrefraction	Super-refraction	Ducting
-79 < dN/dh <=0	dN/dh > 0	-157<dN/dh<=-79	dN/dh <-157
79< dM/dh<=+157	dM/dh > 157	0 <dM/dh<= 79	dM/dh<=0

1. Subrefraction

When the gradient dN/dh within a tropospheric layer is weaker than the standard gradient or is positive i.e, dN/dh > 0 N/km, the radar waves will bend downwards less than would occur in the standard atmosphere and may even curve upward from the line-of-sight that results in less refraction or bending than normal. The condition of dN/dh > 0 is known as subrefraction. This causes shortened ranges on surface-to-surface systems and on surface-to-air systems operating at lower altitudes. A subrefractive layer may cause the radar to misinterpret the position of a distant target. The target position will appear to be at a longer range and at a lower altitude than actual.

2. Super-refraction

Super-refraction can be defined as a condition during which dN/dh within a layer is more negative than that observed in the standard atmosphere, but not negative enough to cause trapping. The waves are bent downward towards the earth more than normal and results in extended ranges. This condition is called superrefraction. It increases the ground coverage of the radar (for shallow angles) and has a little effect on higher angle coverage. The target position will also be misinterpreted. Target will appear to be closer and at a higher altitude than it actually is.

3. Trapping or Ducting

This is an extreme case of super-refraction where dN/dh is very strongly negative i.e, N decreases with altitude much faster than normal. In fact $dN/dh < -157$ N/km, whereas the normal is -40 N/km. The radar waves will refract or bend downwards with a curvature equal or exceeding the earth's curvature. Such an effect causes 'trapping or ducting'. The rays transmitted within the duct will be partially confined to be channeled between the top and bottom of the duct much like in a waveguide. While the radar wave refracts towards the sea surface, it gets reflected upwards from the sea. It is this continuous refracting down and reflecting up and allows for surface detection beyond the normal horizon. The different categories of refractivity are shown pictorially in Figure 4.

4. Meteorological Conditions for Ducting

For a duct to exist, the temperature must increase and/or the humidity must decrease with height, which is obvious from Equation 3. An increase of temperature with height is called a temperature inversion and occurs when the temperature of the sea or land surface is appreciably less then that of the upper air. A temperature inversion must be very pronounced to produce super refraction.

Ducting occurs when the upper air is exceptionally warm and dry as compared to the air at the surface. The stratification of the atmosphere is dependent on certain types

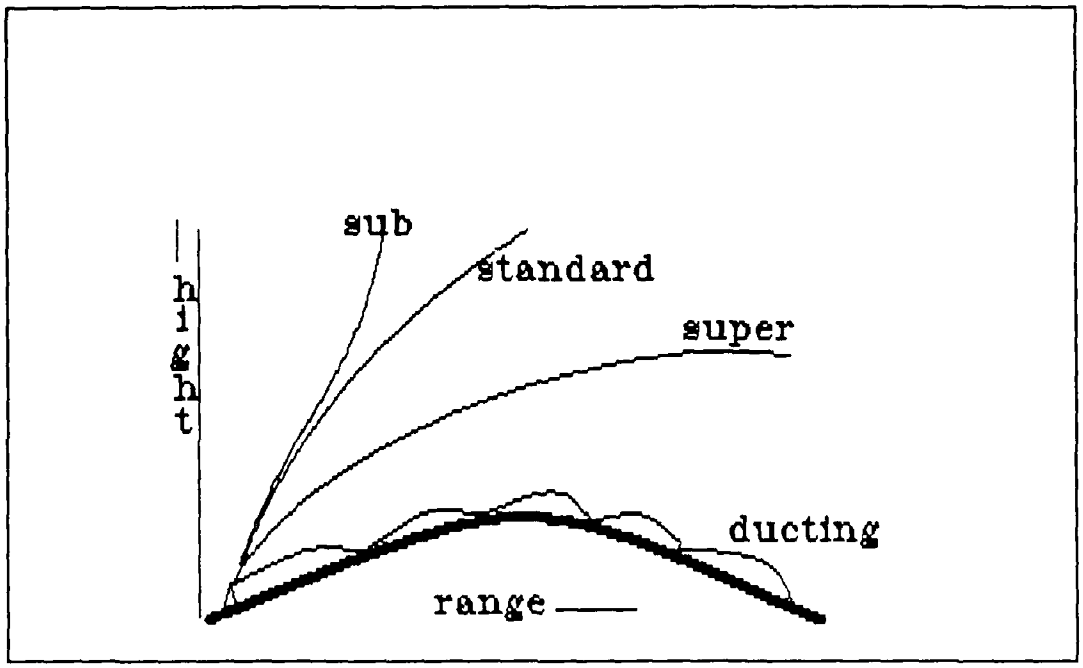


Figure 4 Propagation through the atmosphere for different vertical gradients

of weather to cause anomalous propagation. Equation 3 suggests the importance of moisture or water vapor contents in the air. It has been established that moisture contents of the atmosphere contributes more towards the refractive gradient of the atmosphere than the temperature gradient. That is why super-refractive conditions are found to be more prominent over oceans, specially in hot climates. Sea breeze, high pressure areas, trade wind circulations and high moisture layers produced by surface evaporation or clouds are some of the significant phenomena that cause inversions.

Trade wind inversions are believed to be significantly present in the subtropical ocean areas and their presence is evident by high ducting probabilities. High frequency of

occurrence of elevated mid-level ducts in the Arabian Sea, Persian Gulf and many other parts of the world can also be attributed to the presence of elevated layers. Such warm and dry layers will trap the cool, moist air at the surface and produce rapid increase in temperature and a sharp decrease in moisture to produce a very sharp vertical refractivity gradient responsible for the ducting.

The presence of stratus cloud tops seen by a satellite can indicate the presence of super-refractive layers. Another common cause of ducting is the movement of warm dry air from land on to the cooler bodies of water. The warm dry air that is blown out over the cooler sea is cooled at the lowest layers and cause a temperature inversion. Also the moisture is added from the sea to produce a moisture gradient at the same time. The inversion caused by the sea breeze circulation produce ducting and super-refractive layers as shown in Figure 5.

The differential land-sea heating will cause a warm and dry layer to be above a cool and moist layer. This kind of inversion is limited to upto 75 kilometers from the coast. The same stratification is produced on a much greater scale in the monsoon regions by land breeze in the winter monsoon and sea breeze in the summer monsoon. Ducting can occur during both day or night but is most likely to occur in the late afternoon and evening when the warm afternoon air drifts out over the

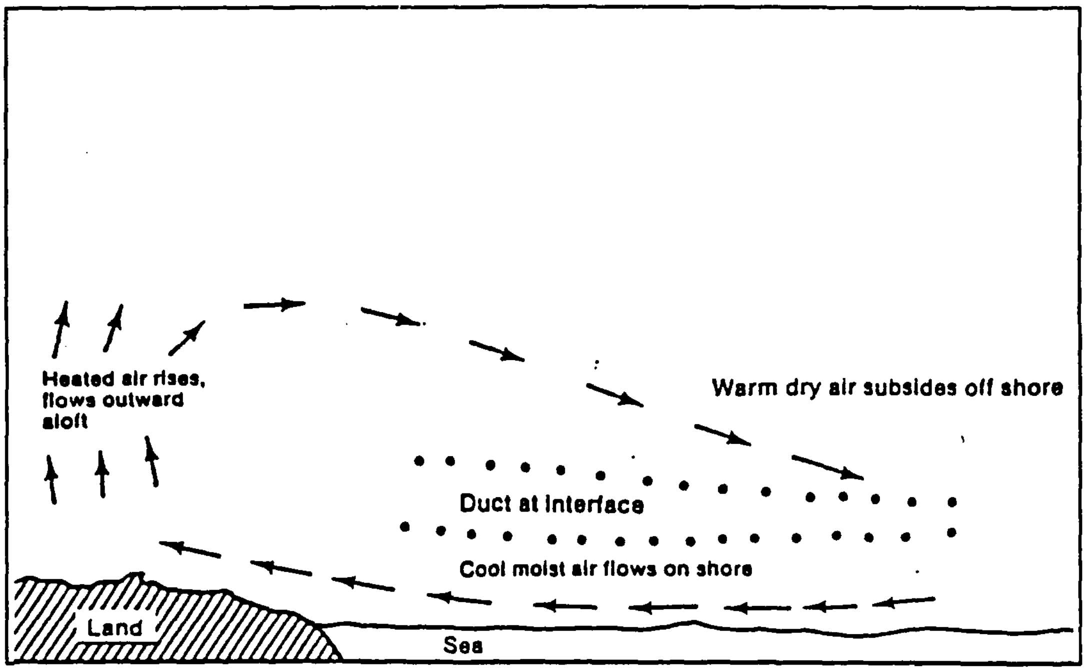


Figure 5 A duct created by a sea breeze circulation

sea. Ducting is basically a fair weather phenomena. Generally fair weather is associated with subtropical (but not equatorial) climates. That is why we find that the most intense ducting occurs in such regions. In temperate climates ducting is more common in summer than in winter. An atmosphere mixed by convection usually does not support ducting. The phenomena of ducting is associated with three distinct types of ducts, surface, evaporative, and elevated ducts, Patterson [Ref. 6].

a. Surface Ducts

In Figure 6, the modified refractivity,**M** is plotted against altitude for a surface duct. Here **M** increases with height in one region, and a trapping layer is formed. If the

M value at the top of the trapping layer is less than that at the surface, a surface or ground based duct is formed.

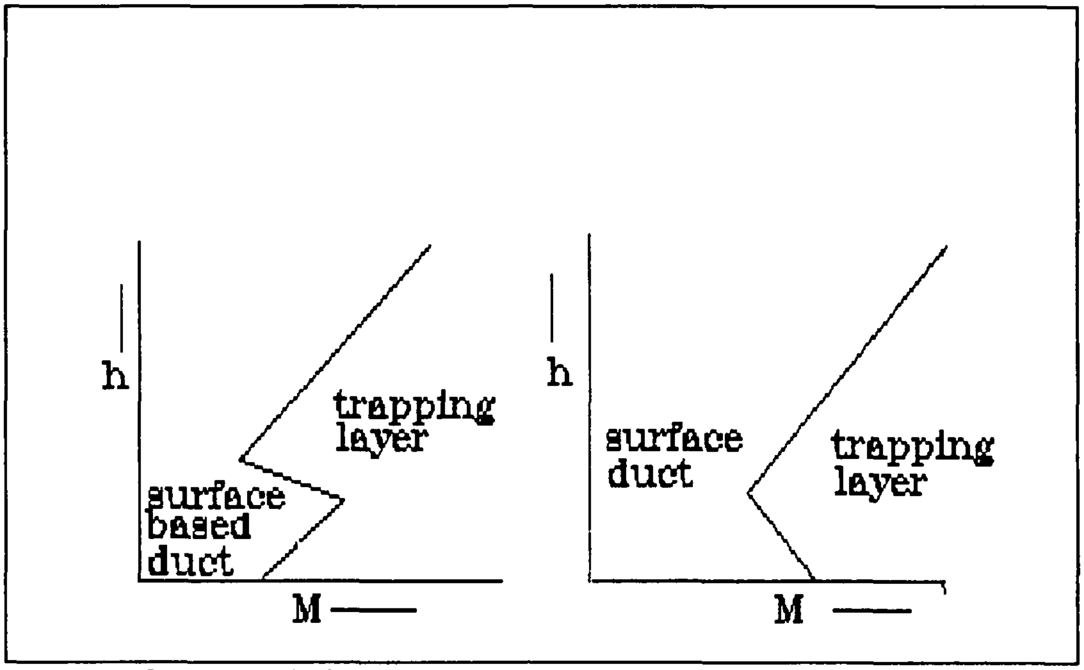


Figure 6 Modified Refractivity M Profile for Surface Duct created by Surface Trapping Layer and an Elevated Trapping Layer.

To propagate energy within the duct, the angle the radar ray makes with the duct should be small, usually less than one degree. Only those rays launched nearly parallel to the duct are trapped. With surface radar, ducting is limited to low angles of elevation so that the major effect is to extend the surface coverage. Surface ducts generally gives extended detection, intercept, and communication ranges for all frequencies above VHF (100 MHZ), provided that both transmitter and receiver are near to or within the duct. Surface ducts also can result in greatly increased levels of land or sea clutter from ranges normally well beyond the

horizon. An often occurring feature of surface based duct is a skip zone near the normal horizon in which the duct lacks influence. This skip zone can be seen using a ray trace program.

Surface ducts are nearly always less than one kilometer thick, and thickness up to 300 meters are most common. They occur annually 8% of the time worldwide, varying geographically from 1% in the North Atlantic to 46% in the Persian Gulf [Ref. 7:p. 3]. The extension of the radar range within the duct results in a reduction of coverage in other directions. The regions with reduced coverage are called radio or radar holes. If for example, the radar range is extended against the surface targets by the presence of a surface duct, air targets just above the duct that would normally be detected might be missed. The shipborne radar pattern is also severely diverted down by the elevated layers. This behavior leaves higher elevation targets uncovered and cause excessive clutter. In addition a ray diverted away from its intended direction, may detect a target; the radar system will indicate the target to be along the originally intended direction, but at the wrong height. This is commonly called "Height Error", as shown in Figure 7.

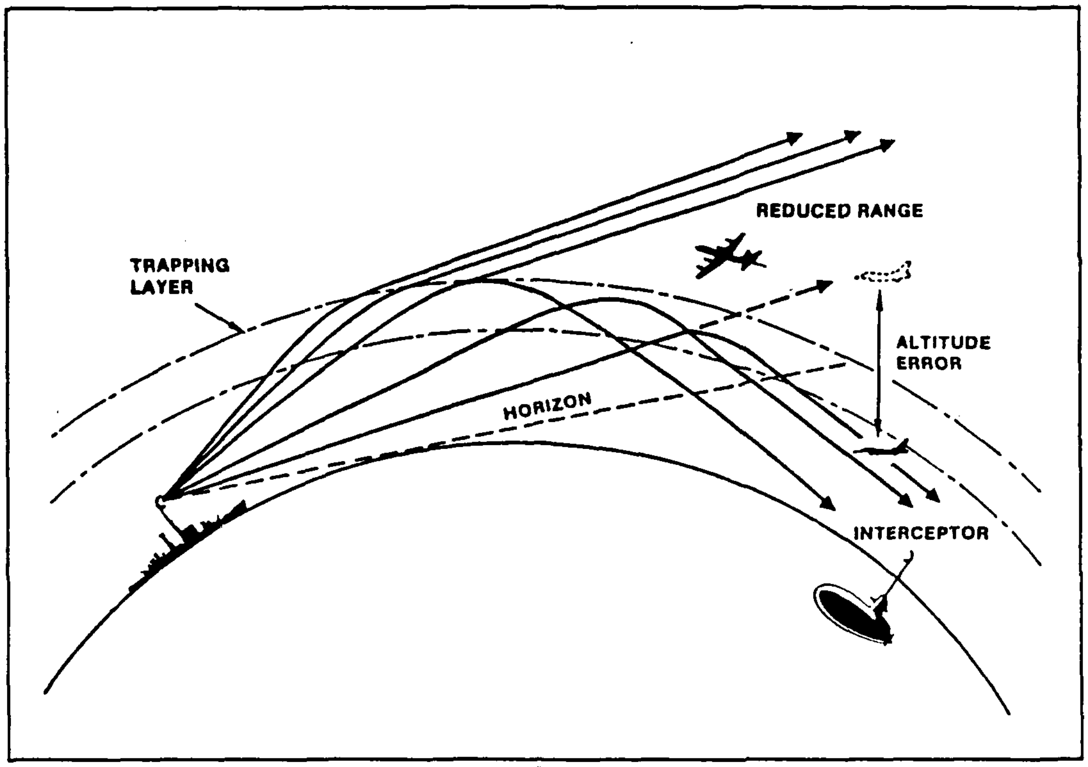


Figure 7 Altitude Error due to Refraction.

b. Evaporation Ducts

Evaporation duct is really a surface duct that is created by the extremely rapid decrease of moisture, water vapor or humidity immediately adjacent to the sea surface. Being close to the sea surface the adjacent air is saturated with water vapor and the relative humidity is 100% there. Within the first few meters the relative humidity decreases sharply to an ambient value that depends on various - meteorological conditions. The decreasing humidity creates a trapping gradient adjacent to the sea surface that gradually becomes weak with increasing altitude till at a certain altitude the modified refractivity **M** is minimized and dM/dh

becomes zero. Further increase from this altitude will cause **M** to increase. This height is referred to as evaporation duct height and is a measure of the strength of the evaporation duct.

The evaporation duct exists over the oceans almost all the time [Ref. 6:p. 26]. The duct height ranges from 6 to 30 meters and varies with geographical locations, seasons, time of the day, and wind speed. Generally duct height will be greater at altitudes near the equator, during the summer season and during day hours. The height of evaporation duct can be readily calculated from measurement of the surface water temperature, the air temperature, wind speed, and relative humidity. These four measurements are sufficient for describing the ducting conditions.

Generally the evaporation duct will only affect surface-to-surface electromagnetic wave systems, above UHF frequencies, although some affects can also be observed during low flying missions. The evaporation duct height is only a measure of the strength of the duct and is not to be taken as a height below which an antenna can be placed to obtain extended ranges. For a given surface search radar a strong duct will extend the detection range and for sufficiently large duct heights, targets can be detected at greater ranges beyond the horizon. The same operational performance in interception of surface-to-surface paths at greater ranges by ESM is obtained. Ship-to-ship UHF communication frequencies

are too low to benefit from the evaporation duct, but UHF ranges can be extended by surface based ducts.

c. Elevated Ducts

If the value of **M** at the top of the trapping layer is greater than that at the surface, an elevated duct will be formed as shown in Figure 8.

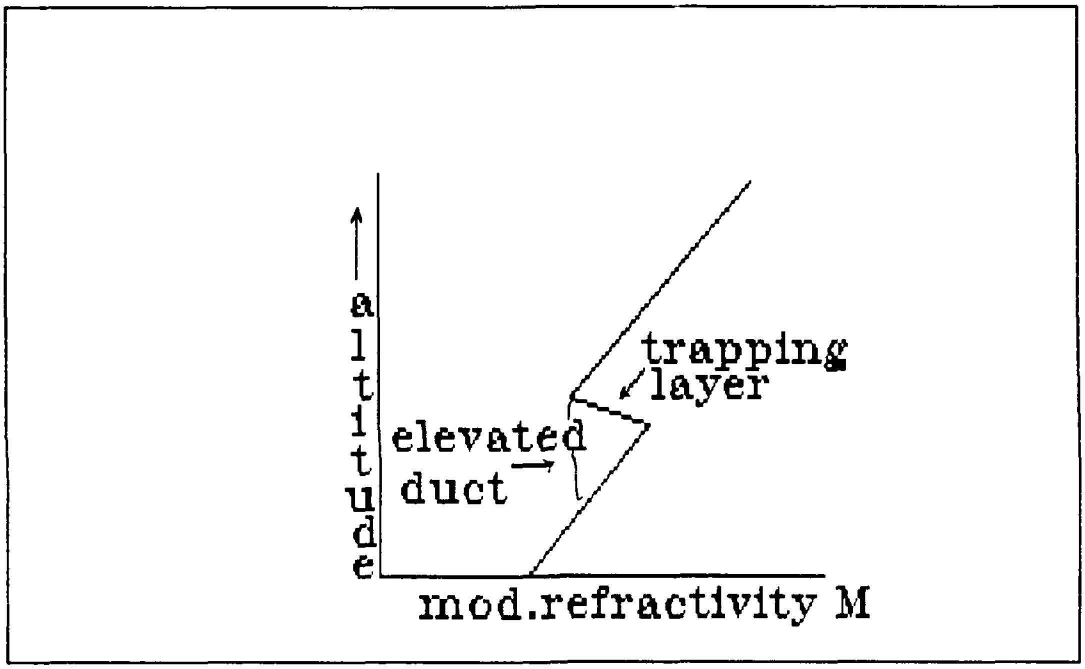


Figure 8 An elevated duct created by an elevated trapping layer

Elevated ducts are formed primarily when a temperature inversion at higher altitudes causes a trapping layer that is sufficiently high that no rays from a surface source can be trapped. These temperature inversions can be caused by the intrusion of warmer, drier air into the region above the cooler moist air or by sinking or subsidence of air under

higher pressure centers. Because of the intrusion of drier, as well as warmer air, a faster than normal decrease of humidity with height usually accompanies the elevated temperature inversions. This results in a strong duct along the interface of the temperature inversion.

Since the angle between the radar beam and the duct direction cannot be greater than about one degree, if the power is to be coupled into an elevated duct, the radar must usually be at an altitude that allows required shallow coupling angles to be achieved. That is why the radar in this case would be more sensitive to the targets within the duct than those outside it. Elevated ducts can trap rays only from an elevated source, and therefore are most important when assessing airborne system performance.

The source heights for which the trapping can occur are from the top of the trapping layer to the height below the trapping layer at which the **M** value is same as at the top of the trapping layer. For source heights above the trapping layer, there will be combinations of ranges and altitudes to which no rays can penetrate. Such regions are the radio holes as shown in Figure 9.

Elevated ducts can occur more than 50% of the time in many areas of the world at altitudes from near zero to 6 km, although maximum altitudes of 3 km are more common [Ref. ':p. 3]. Higher frequencies are more likely to be trapped. Although there is a lower frequency limit of ducting

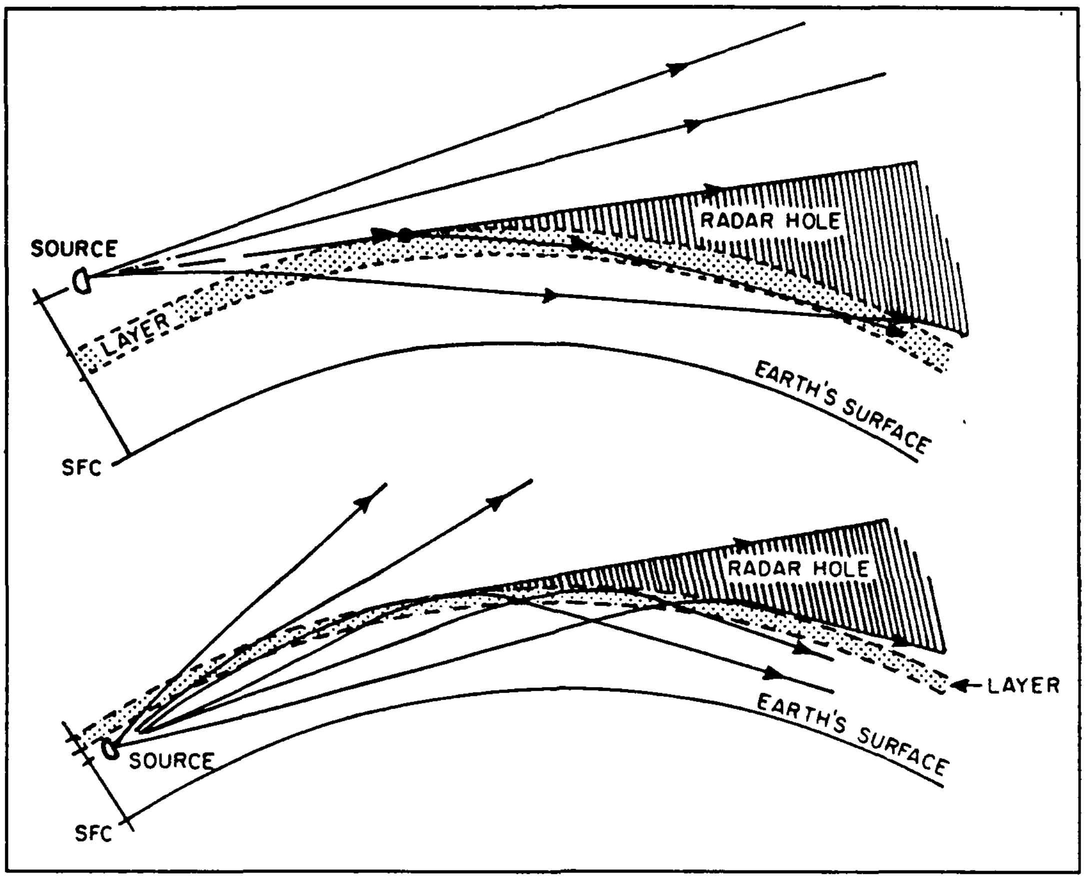


Figure 9 Ray refraction by an elevated layer for radar just above and just below the layer

associated with the thickness and strength of an elevated duct, for most practical situations the limit is below the normal radar bands, and effects from elevated ducts are therefore considered to be frequency independent. Many electromagnetic systems are exposed to anomalous propagation caused by elevated layers. Air to air surveillance, communication, electronic warfare and weapon guidance systems are strongly effected. Antennas used for communication, telemetry, airplane instrument landing system, and radar are also primary candidates either because of their physical

proximity to the anomalous elevated refractive layer or because their ray path passes through these layers.

Thermal heating from the sun will induce a temporal change in the height of the boundary layer. This would likely to cause an elevated duct to migrate up and down thereby causing coverage problem to vary in its severity according to the time of the day.

III. ARABIAN SEA CLIMATOLOGY AND REFRACTIVE STRUCTURE

Initial efforts in this thesis research were to obtain radiosonde data for the Arabian Sea for the analysis. Composite refractivity profiles for the area were to be based on this analysis. To pursue that goal a data set from Fleet Numerical oceanographic Center (FNOC), Monterey, was obtained for the Arabian Sea for the year 1988. The huge data file was on a 9-track magnetic tape which was transferred to a main frame computer. One of the objective was to bring the data into a form which could be read by the personal computer based EREPS so that the effect of ducting on the radar and ESM performance could be studied for the given conditions.

The large file on the main frame was partitioned into smaller portions and was transferred to the floppy disks. The data consisted of radiosonde launches from different coastal, inland stations and from ships at sea for routine radiosonde launches at two fixed times during the day , 0000Z and 1200Z. After a considerable effort of checking the data, it was found that the data had scarce number of ships radiosonde launches. The number were considered insufficient to be used for a meaningful refractive analysis of the area. This effort brought one important point into the light. This is that the Arabian Sea, Figure 10, is a relatively data poor area. Although lots of data were available from a number of coastal

stations such as Karachi, Bombay, and Oman etc, very little data is available for over the sea area.

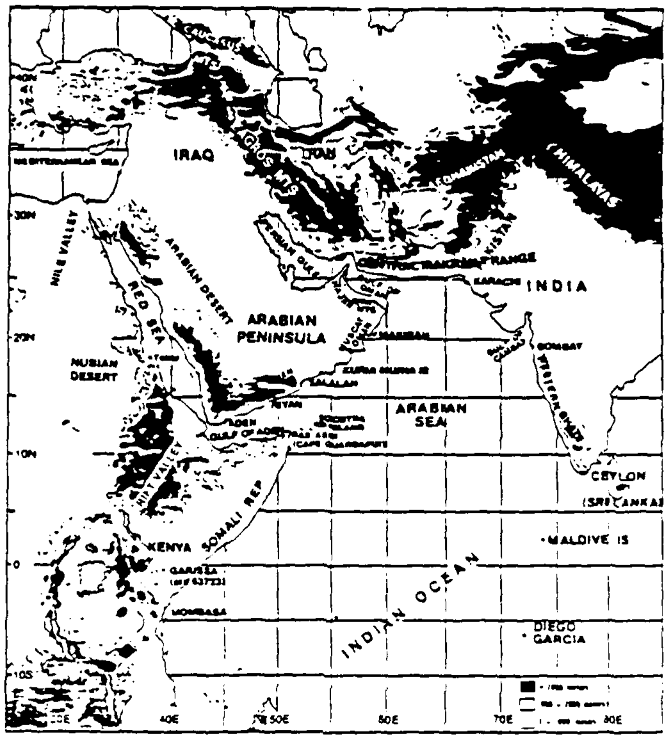


Figure 10 Map of Arabian Sea region

The above mentioned result led to the refractive description of the Arabian Sea being based on Lammers [Ref. 8]. Ortenburger [Ref. 9] derived worldwide refractive layering information from standard meteorological radiosonde data provided by the USAF Environmental Technical Application Center (ETAC). Worldwide contour maps pertaining to the percentage of occurrence of elevated ducts prepared by Lammers, based on radiosonde data analysis of Ortenburger, are used to present a very general refractive conditions in

Arabian Sea. Results of IREPS analysis on data collected by USS KENNEDY (CV-67) in the North Arabian Sea is also presented [Ref. 10].

The Arabian Sea is located within the most famous monsoon regions. The term 'monsoon' is a name for seasonal winds and is the English adaptation of the Arabic word 'mausim', meaning season. In general the term describes the regime where there are highly persistent winds from nearly opposite directions in summer and winter. The land masses are warmer than the ocean areas in summer and cooler in winter, resulting in relatively lower pressure over the land in summer and higher in winter. The pressure differences cause winds to blow primarily onshore (summer) and offshore (winter). The monsoon are characterized by two distinct seasons separated by two short (30 to 45 days) transition periods. They are explained in more detail later in this chapter with the help of explanation from Ref. 12 and Ref. 13.

TABLE 2

North-East or Winter Monsoon	December - March
Spring Transition	April - May
South-West or Summer Monsoon	June - September
Fall or Autumn Transition	October - November

Relative Humidity immediately over the Arabian Sea and Indian Ocean is remarkably uniform and shows a very little variation throughout the year. The maximum relative humidity of 87% occurs in August and a minimum of 78% occurs in April. Lammers [Ref. 8] presents an annual percentage of occurrence of elevated ducts in the Arabian Sea as shown in Figure 11. A likelihood of 40% elevated ducting exists at all times in the Western part of the Arabian Sea with 30% in the central part of the sea.

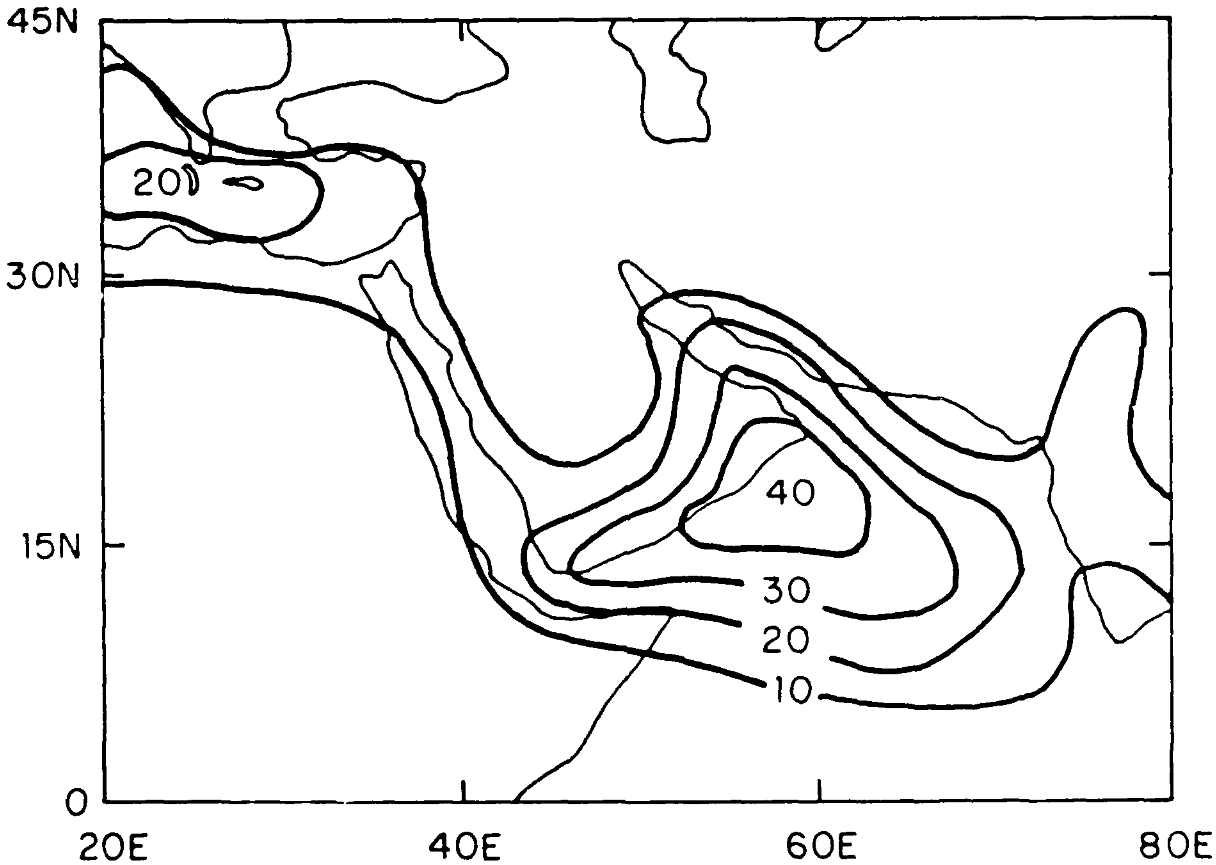


Figure 11 Annual percentage occurrence of elevated ducts [Ref. 8].

A. NORTH EAST OR WINTER MONSOON (DECEMBER-MARCH)

The conditions during the winter monsoon are primarily dominated by the off-shore, North-Easterly wind. Dry air is being advected into the region. The weather is generally fair. The temperature is moderately warm with almost clear skies [Ref. 11]. Humidity is fairly low during this period. Higher temperatures are also some times encountered. The Northeast monsoon blows steadily (about force 4) over most of the Arabian Sea and becomes more Northerly along the Indian coast. Land and sea breezes are felt on the coast. The rain fall varies from year to year. Northern part of the sea experiences heavy rains during some years, but at times it does not rain at all during the whole year. On the coastal city like Karachi the climate can be pleasant and at times even cool due to low humidity. There are little clouds and there are many days with clear skies. There are very few cyclonic storms during this period. A well defined low and frontal system exist in the Northwest near Gulf of Oman, otherwise a flat pressure field exist over the whole area. Strong surface based ducts with top near 2,000 feet occur with a percentage of occurrence of 25%-40%. Moderate temperature inversions exist. Figure 12 show that the area of 40% frequency of occurrence of elevated ducts covers a major portion of the Arabian Sea during these months. Strong surface ducts will cause surface-to-surface ranges to be greatly extended.

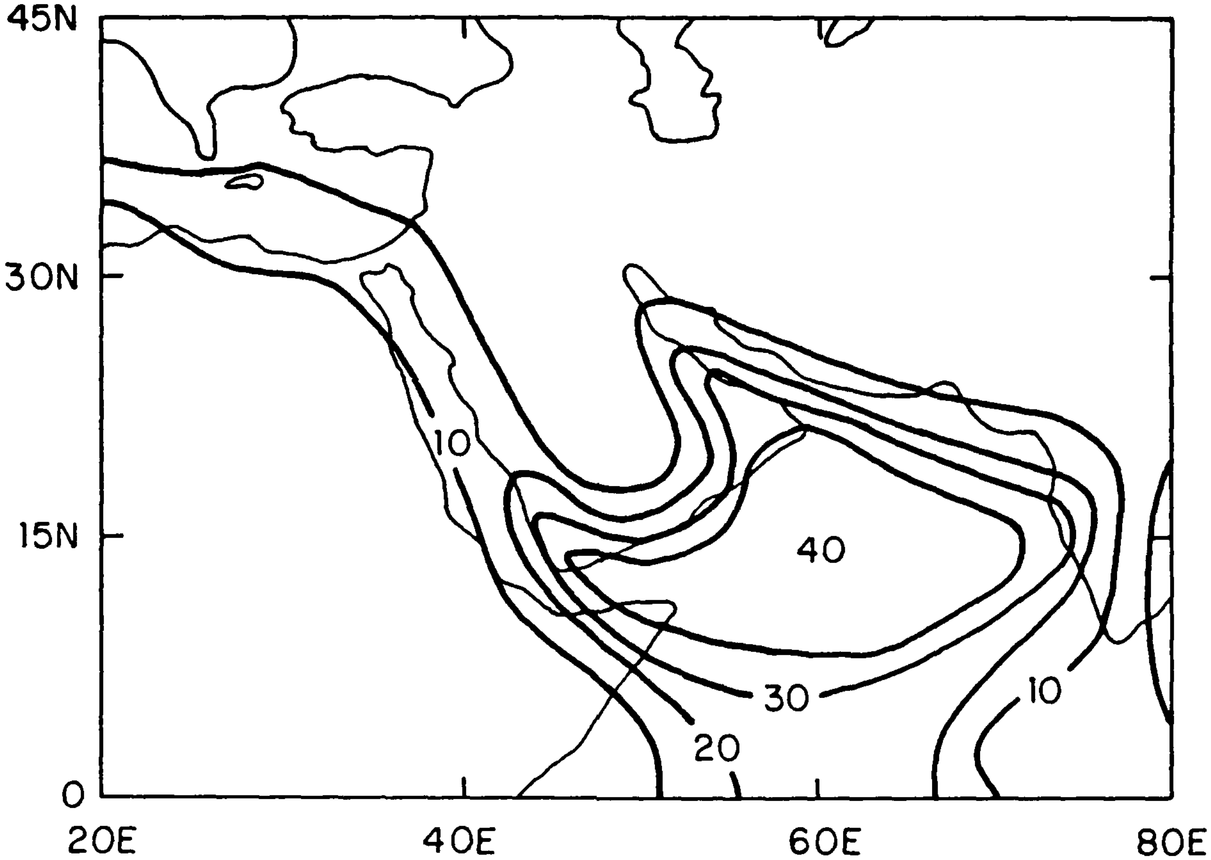


Figure 12 Percentage occurrence of elevated ducts - February, March, April [Ref. 8].

B. SPRING TRANSITION (APRIL-MAY)

During this period the winds in the area are light and variable. The wind start changing direction from North-East to South-West. Alternating advection of dry air from the North and moist air from the South provides a variable atmosphere. As a whole the weather is fair and hot (80-85 F) over the sea upto the end of April after which it starts becoming less settled. Moist air from the South brings cloudier and more sultry conditions with frequent squalls and showers in the central region. The North Arabian Sea remains rainless with

little cloud and good visibility. Winds are more variable than at the height of monsoons. Near the coast of India most wind blow from between North and West (force 2-3) while along the Arabian and Makran coast Southwesterly westerly winds of the same strength predominates. Strong tropical storms occur about once in five years originating in the Southeast. They travel about parallel to the Indian coast and pass across the head of the Arabian Sea to the entrance of the Persian Gulf or the Arabian coast near Ras-ul-Hadd. They tend to follow Northwesterly path. Generally a standard well mixed atmosphere which shows no significant refractive layers. During this period the 40% occurrence region of elevated ducts has moved further down to the Indian ocean as seen in Figure 13. Surface ducts are not significantly present. Generally all radar coverages are normal except for some minor effects of elevated layers.

C. SOUTH WEST MONSOON (JUNE-SEPTEMBER)

During the Southwest monsoon the wind blows steadily and strongly from the sea. On the average, June is the hottest month of the year over most of the region. By the end of june the Southwest monsoon causes the temperature to fall slightly to 80-82F in July and August. The indication of the arrival of Southwest monsoon is a falling barometer and a heavy swell from Southwest or Westerly direction. Rough seas and a heavy swell are experienced throughout the season. The relative

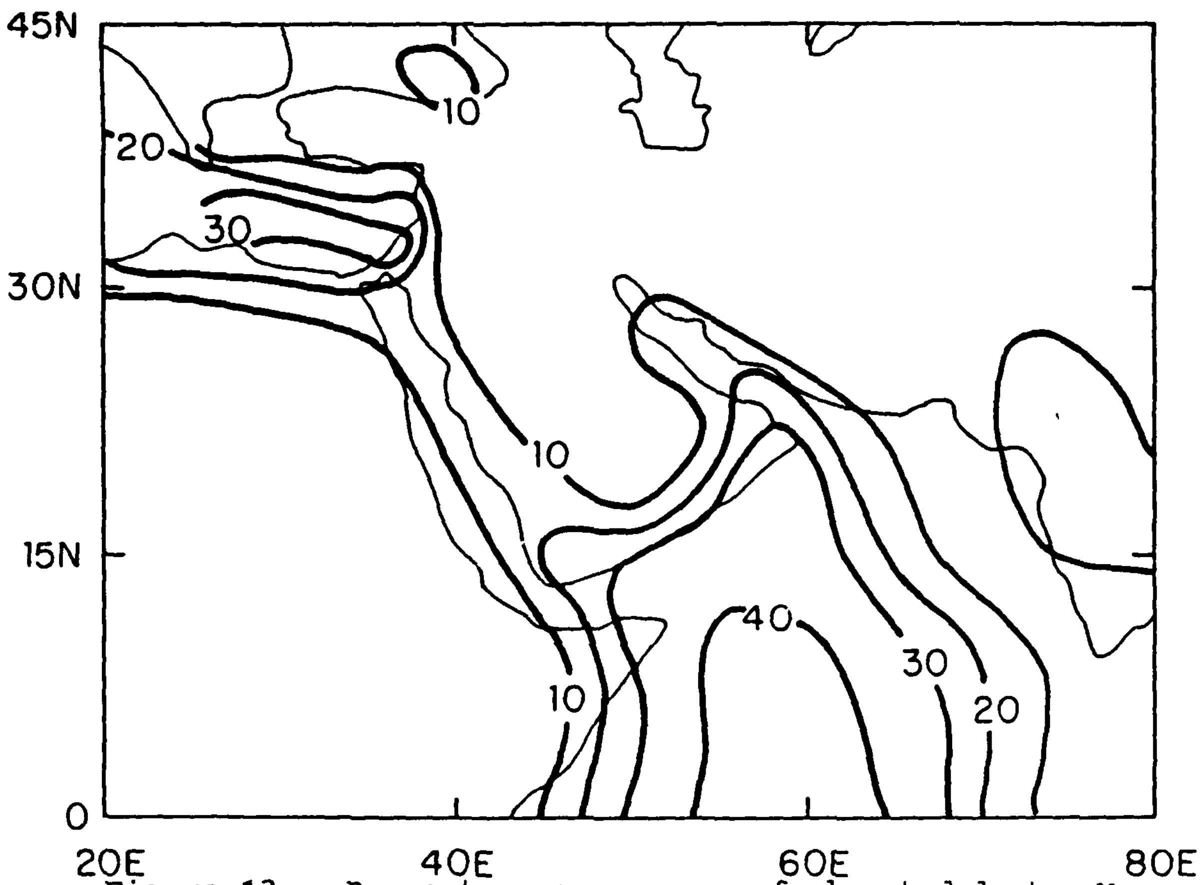


Figure 13 Percentage occurrence of elevated ducts -May, June, July [Ref. 8].

humidity is comparatively high throughout this period and August is usually the month of highest relative humidity. General conditions are humid, cloudy and showery with the strong squally winds. The skies are much overcast then during other months of the year, with generally low cloud bases. Visibility is generally about 10 miles. Southwest winds of about force 5 predominates over most of the sea. Cyclonic storms are almost unknown but the monsoon may strengthen to force 8-10. During the early phase upto July, frequency of occurrence of elevated ducts is from 20% to 30% as indicated

in Figure 13. The frequency gradually increases to 40% in the Western half of the region. This is illustrated in Figure 14. This region of 40% occurrence is much smaller than that during the winter monsoon.

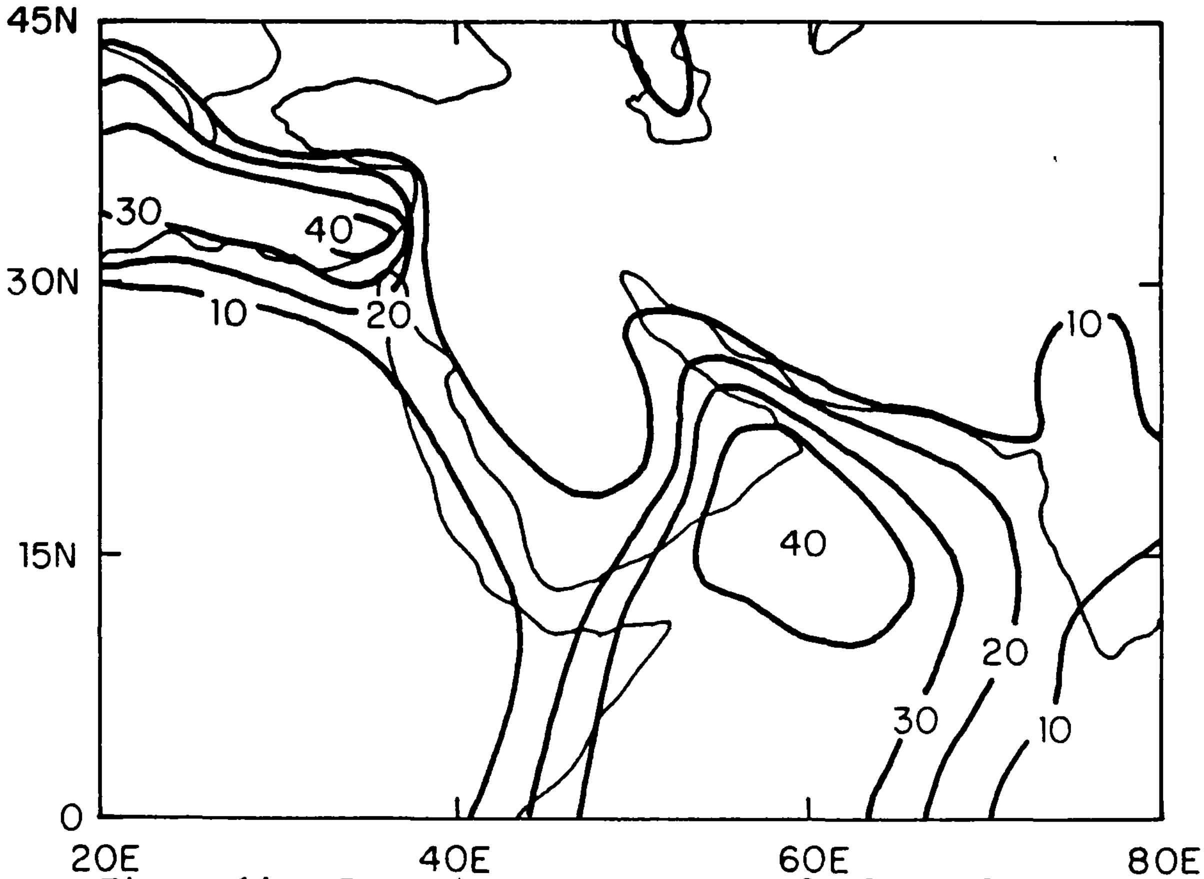


Figure 14 Percentage occurrence of elevated ducts - August, September, October [Ref. 8].

Surface ducts have comparatively greater frequency of occurrence on Western side of the Arabian Sea then the Eastern part. Along the Indian coast strong elevated subrefractive layers due to strong increase in moisture at higher levels are found that can cause holes and possible fading for systems at those altitudes.

D. FALL TRANSITION (OCTOBER-NOVEMBER)

The surface winds over the whole region become light and variable but mainly from the Westerly direction. Land breeze from the Arabian Peninsula and sea breeze also prevail. In general a fair weather with light winds prevail over the area, particularly in the Northern part. Temperatures are around 80 F or more. There are considerable periods of fine weather with little clouds, alternating with shorter periods of cloudy, squally and showery weather associated with intertropical front. Flat pressure field prevails over most of the region. The surface winds over the whole region become light and variable but mainly Westerly. Land and sea breeze also prevail. The relative humidity falls with the withdrawal of the Southwest monsoon and the values of relative humidity in October are about 10% below those in september. The Northeast monsoon winds normally starts blowing in November, first over land and then over sea by mid November. Visibility is good and skies in the Northern part are clear. Winds are variable but Northerly direction is predominant [Ref. 12]. Surface ducts are present 20% to 30% of the time whereas elevated ducts are present 40% of the time on the Western part and 20 to 30% in the Eastern part of the Arabian Sea as shown in Figure 15.

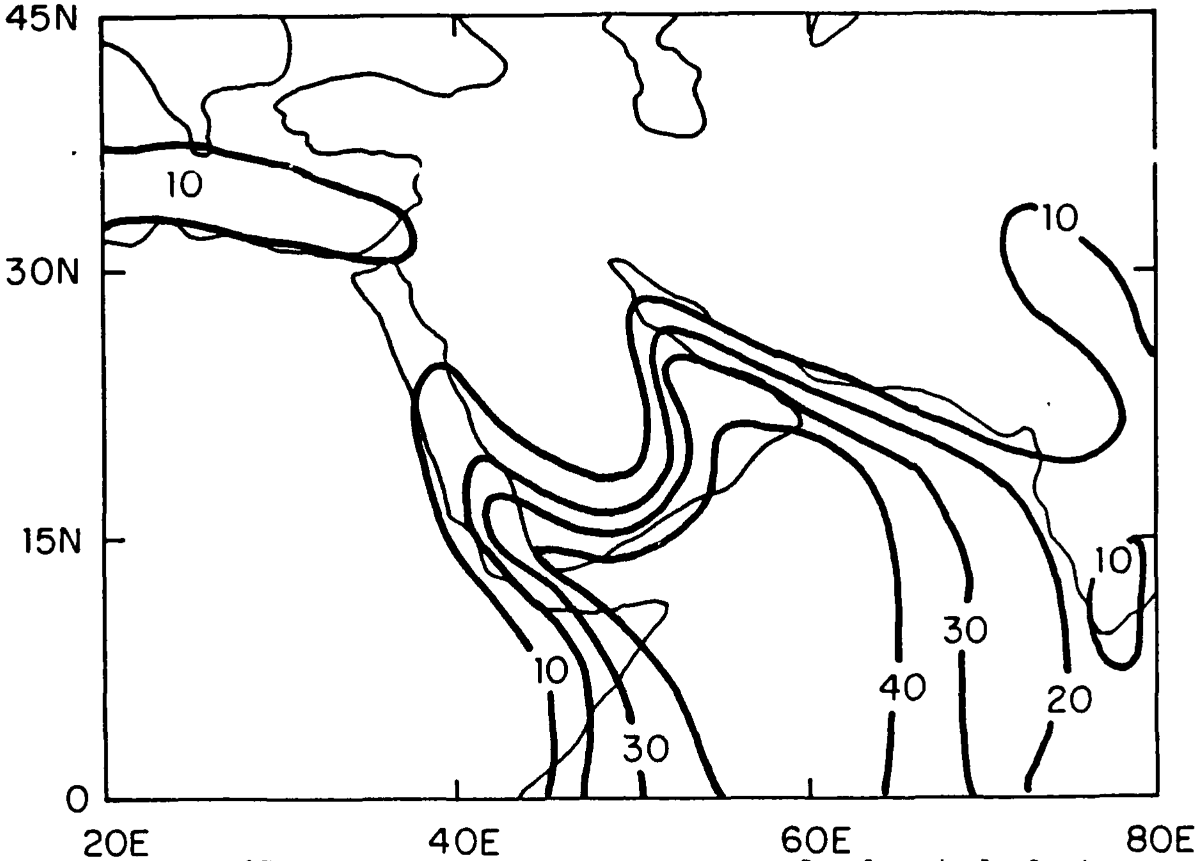


Figure 15 Percentage occurrence of elevated ducts - November, December, January [Ref. 8].

E. RESULTS OF USS KENNEDY DATA ANALYSIS

The USS Kennedy carried out radiosonde launches twice a day while deployed in the North Arabian Sea in 1982. The data collected were analyzed using IREPS for a period from February through April 1982. An analysis on these data was carried out by Grau [Ref. 10:p. 24-27]. A frequency distribution of the trapping layers and a box plot is shown in Figure 16 and Figure 17. His results indicated presence of elevated ducts in the area 65% of the time, Figure 16. These elevated ducts

generally formed between 2,000 ft and 7,000 ft with a mean of 3,840 ft and a standard deviation of 2,000 ft, Figure 17. The highest frequency of occurrence of trapping layers were found to be around 5000 ft. During the months of February and March, in the winter monsoon period, the percentage of occurrence of elevated trapping layers at 5000 ft varies between 50% to 70%. Other elevated trapping layers of various heights also occur as shown in Figure 16.

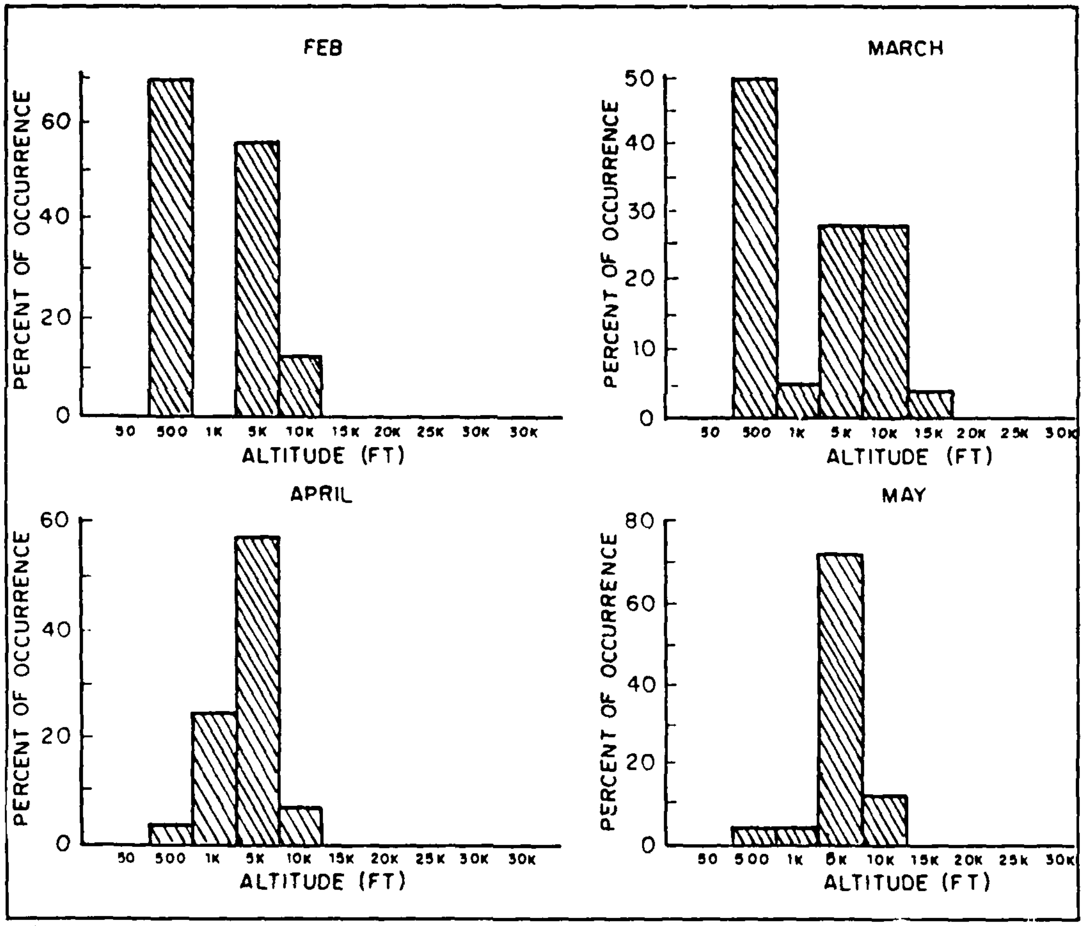


Figure 16 Frequency of trapping layers [Ref. 10].

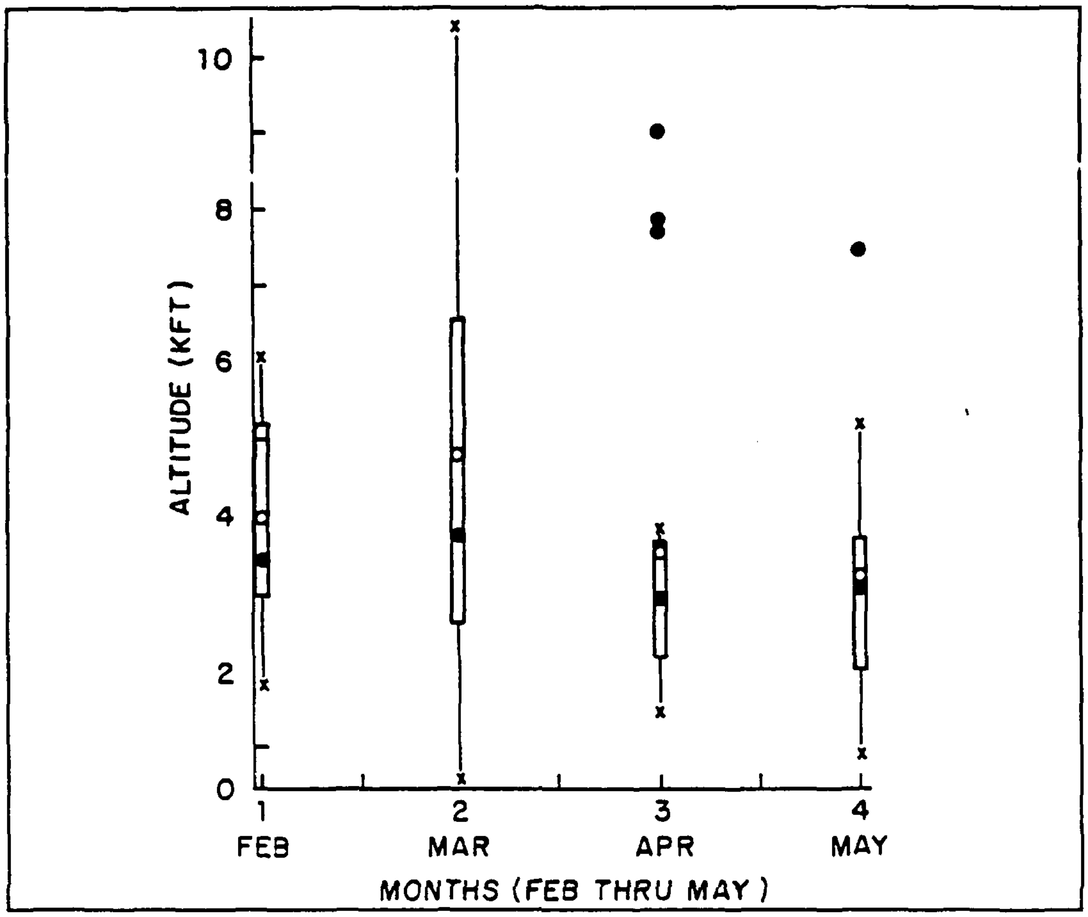


Figure 17 Boxplot of trapping layer data

IV. REFRACTIVE CONDITIONS AND ELECTRONIC WARFARE

A. ELECTRONIC SUPPORT MEASURES (ESM)

The lethality, short reaction time, and intensity of modern combat necessitate earliest possible detection of hostile forces in order for a timely and effective response. Therefore, long range, Over The Horizon (OTH) detection and targeting is of paramount importance at sea as modern naval operations demand early detection and expanded battle space. With suitable intercept equipment having adequate sensitivity to receive microwave signals by the scatter and atmospheric duct modes of propagation a ship can obtain very long range warning, up to several hundred miles.

ESM provides the earliest warning of enemy presence. The task of early detection of approaching missiles or aircraft is further complicated due to reduction in radar crossection, reducing radar detection range. Considering these, the survival of a task force at sea has to rely heavily on early detection, operation deception and fire power or hard kill of the attacking aircraft before it launches its missiles, so timely threat detection and recognition have become vital prerequisites for an effective use of the tactical response options.

ESM is used specifically for tactical purposes to learn what is out there and what enemy weapon system radiation is being intercepted. It requires immediate actions to take care of that situation as compared to similar functions that are carried out for intelligence gathering, where the purpose is to find out what is it, how it works, and all the possible information you can derive on further analysis. ESM detection range is a major factor in ESM reconnaissance or surveillance employment and tactics.

Consideration of the ESM detection range, which is geometrically constrained due to line-of-sight considerations, relative to the target detection ranges of hostile radar systems and lethal ranges of associated weapons is particularly important. Receiving radar signals is often not that difficult due to higher power density available to the receiver. The ESM interceptor has the one-way propagation path advantage over the active radar two way propagation path. Power transmitted by radar is proportional to $1/R^4$ where R is the range at which the radar is to detect a target. Power available at the ESM receiver is proportional to $1/R^2$. Therefore the ESM receiver has an advantage in the R^2 versus R^4 path loss over the radar, however the signal to noise ratio available to an ESM receiver may not be very high.

Although ESM detection ranges can be theoretically much greater than radar detection ranges, the effective ESM detection range is considerably affected by the geometric line

of sight constraints which can severely limit shipboard ESM effectiveness against surface targets and low flying penetrators. The ability of the shipboard radar detection capability is also restricted by the Line-Of-Sight (LOS) geometry so that the radar LOS detection range is approximately the same as the effective ESM detection range. Therefore it is justifiable to assume that the enemy has already detected the ESM ship when the ship's ESM intercepts the hostile ship's radar emissions. The same is not true in case of a surface ship ESM detection against an aircraft. If the aircraft is at a higher altitude its radar waves can travel much longer. The shipboard ESM detection range in this case may exceed the airborne radar range if the aircraft is at sufficiently high altitude.[Ref. 13:p. 358]

As described previously, surface and elevated ducts can greatly extend the RF detection and ESM intercept ranges well beyond the visible horizon. Changes in the refractive index of the atmosphere can cause ducting phenomena that can trap the electromagnetic energy. Ducting can cause either reduced or enhanced operational ranges. The ESM intercept ranges are considerably enhanced if both the radar platform and ESM platform are within the surface based or elevated duct or if the emitted energy enters the duct at very shallow grazing angles.

The passive detection capability provided by ESM can be extremely valuable for the OTH detection and targeting.

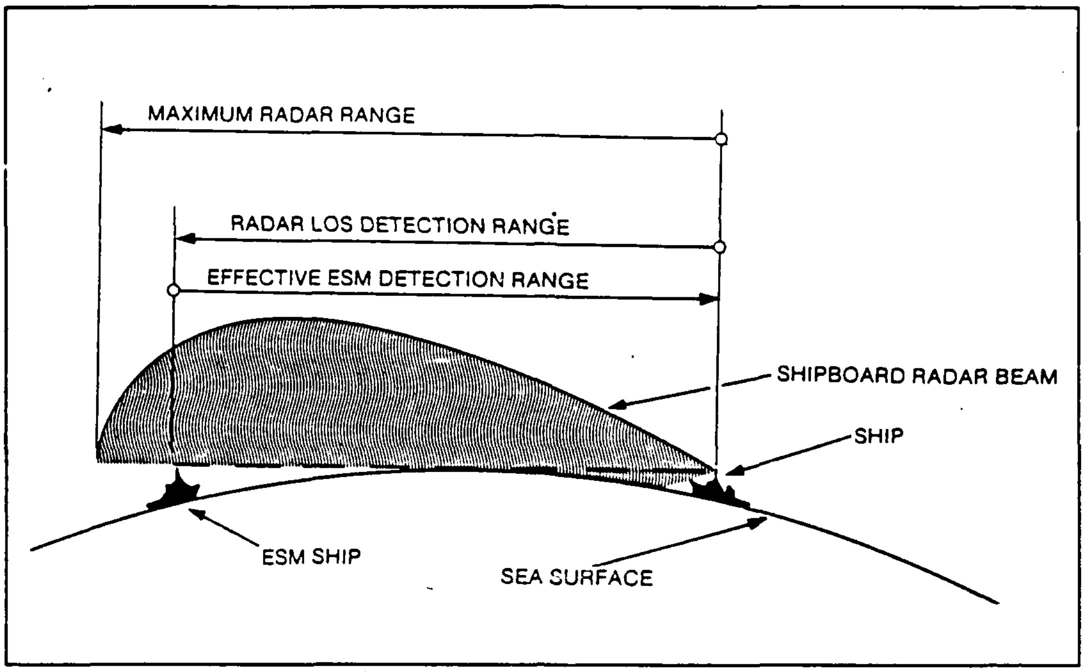


Figure 18 Typical ESM detection range geometry (ship-to-ship)

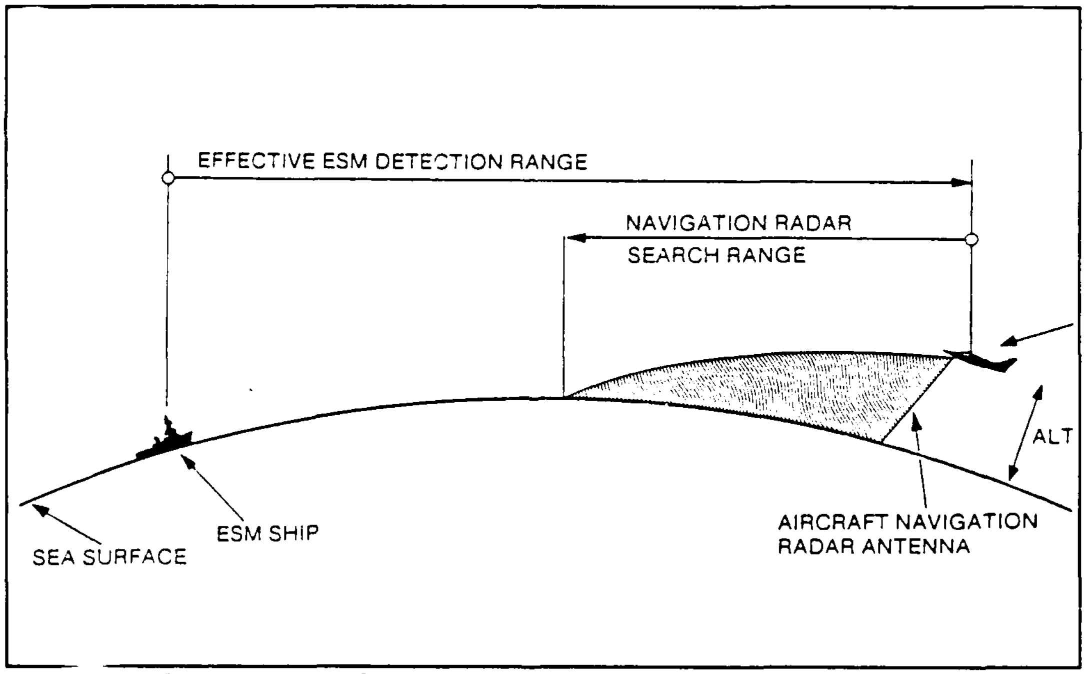


Figure 19 Typical ESM detection geometry (ship-to-air)

HARPOON anti-ship missile can be fired from a ship, submarine or an aircraft to strike an enemy vessel while remaining

outside the target's weapon range. LOS constraints pertaining to ESM detection, however, does not allow the use of shipboard ESM assets for Over The Horizon Targeting (OTHT) support. The knowledge of ducting conditions can supplement to the existing OTHT means. The LOS constraints can be overcome by use of airborne ESM or satellite sensors. An Airborne Early Warning (AEW) and reconnaissance aircraft can greatly improve the probability of detection of enemy or its emissions if the effects of anomalous propagation of radar waves through the environment are considered while deploying such a platform.

B. TACTICAL USE OF REFRACTIVITY

The need to use refractivity to predict the behavior of electromagnetic waves in the troposphere has been long recognized. There have been a number of models used for this application but only in the last decade has it been possible to perform all these calculation and display refractivity effects on EM waves using even personal computers. This enables even a smaller ship to have this capability out at sea to know the near real-time and on-time refractive structure of the atmosphere. At present there are two such PC-based programs which can be used for the prediction and assessment of the EM waves propagation effects, these are IREPS and EREPS. The IREPS program has been used by US Navy for some time for prediction of refractive effects. IREPS uses the shipboard computing capability to generate displays of

predicted EM equipment performance from the inputs of the environment and equipment parameters. It provides the operational performance assessment of specific EM systems using the environmental inputs of pressure, temperature and humidity from the radio-sonde ascent or a refractivity versus altitude profile obtained directly from an Airborne Micrometer Refractometer (AMR), and sea surface temperature, humidity and wind speed.

The various products presently available in IREPS are:

1. Coverage diagrams showing altitude-versus-range plots where a specified radar, communication or ESM equipment will achieve or exceed one or more predefined levels of performance (typical probability of detection of 0.9, 0.5, or 0.1 against a 1-square meter target).
2. One way path loss in db versus range.
3. Table of maximum ESM intercept ranges for a predefined list of emitters.
4. A climatology summary to provide an estimation of ducting conditions on a statistical bases as an aid to long range or long term planning.[Ref. 5]

The EREPS program can be used for assessment of the lower atmosphere on a radar, EW, or communication system. The EREPS models take into the account the effects from optical interference, diffraction, tropospheric scatter, refraction, evaporation and surface based ducting, and water vapors absorption under horizontally homogeneous atmospheric

conditions. Whereas IREPS is designed for operational use, the EREPS is suitable for comparative study of performance of two sensors that may differ by only one parameter, such as radar pulse length, or you can show relative performance of a given system with only one environmental parameter changing its value such as wind speed or evaporation duct height [Ref. 6].

Knowledge of the refractive conditions gives you a definite edge over the adversary. Some of the tactical advantages which may be gained through effectively using the refractivity to your advantage are discussed below.

1. ESM Operations

The presence of surface based ducts generally provide extended ESM intercept of the enemy transmissions for surface platforms. Such interceptions can provide much useful information about the hostile forces. Such information can be used to, confirm the presence of enemy, determine force composition, identify the units, establish a line of bearing, deduce an estimated position, and extract information based on the content of transmission.

In surveillance systems like ESM and ELINT, ducting can help provide such useful information which would otherwise be unavailable. By knowing the enemy's emitter's parameter through your ESM equipment, and your ESM system's sensitivity along with presence or absence of ducting conditions may allow the ESM operator to obtain realistic range estimation of the

enemy's position. Path loss versus range displays in IREPS and EREPS are considered useful for this purpose. ESM intercept ranges for surface-to-surface paths can be greatly extended by the evaporation ducts also. Ship-to-ship UHF communication frequencies are too low to benefit from the evaporation duct but UHF ranges can be extended greatly by the surface based ducts. Intercept range enhancements are greatest when both radar transmitter and the receiver are within the duct. Similar advantages can be obtained for airborne surveillance and ECM operations like jamming, whose effects can be greatly enhanced in the surface and elevated ducts.

2. Survival of Conventional Submarine against ASW Aircraft

A conventional diesel electric submarine will periodically operate at periscope depth, snorkeling to run its diesel engines in order to recharge batteries. This gives ASW aircraft its best chance for radar detection of the submarine. Submarines rely heavily upon ESM intercept through its passive equipment for warning of such airborne radars. The assessment of the threat posed by intercepted radar is vital for the submarine. Although the range of the radar from the submarine can not be reliably estimated because of the wide variations possible in the propagation path due to ducting or atmospheric absorption, the point in time when the submarine could be detected by the aircraft can be roughly estimated. Such a

process of determining this point is known as reciprocal intercept. Interception of aircraft radar by submarine ESM system along with the knowledge of its receiver sensitivity, allows the submarine to dive well before the aircraft is able to detect it. The presence of ducting conditions help the submarine to detect the enemy with sufficient time to take an evasive action.

3. Airborne Early Warning (AEW) Applications

The presence of ducting conditions greatly improves the performance of an AEW aircraft when placed at suitable altitudes. An early warning radar can utilize elevated ducts to increase its detection range for targets located within the elevated ducts if the AEW radar is also within the duct. At the same time a large gap in coverage would extend outward above the elevated duct, and is caused by trapping of that portion of the radio waves within the duct that would normally be in the gap. If the aircraft is stationed at the top of the duct, no enhanced detection capability within the duct can result, but still a large radar hole will be created in the coverage.

Immediate top of the duct is probably the worst altitude to place the radar, since it results in the largest hole. If you increase the altitude further, radar hole would become smaller and smaller and at higher altitudes it would disappear altogether. If you place the aircraft at the very

bottom of the duct, it will result in no hole at all. Any radar altitude below an elevated duct will not create a radar hole and can therefore be taken to be suitable location to minimize the radar hole. Air to air communication and ESM systems are similarly affected.

Position of the AEW aircraft is totally dependent on the type of mission it is performing. If the object is to increase the radar range against surface targets then the aircraft can fly at higher altitudes as applicable. For detection and early warning of high altitude targets the AEW aircraft will have a better performance if it flies below the lowest significant elevated ducts while remaining above any surface ducts. For ESM detection of airborne targets inside an elevated duct, the AEW aircraft could be best placed inside the duct. For unknown target altitudes flying at higher altitudes will give better intercepts. For surface targets ESM detection the AEW aircraft give better performance while stationed within the surface duct or while it is flying at higher altitudes.

Figures in Appendix A are the pictures of radar display of an AEW aircraft operating over the Arabian Sea during different ducting conditions. The curved fanlike echoes extending outward from the center of the PPI are the pulse interference and the white corridor extending outward in some of the pictures is some kind of broadband noise or interference. Surface targets appear as arcs because of

relatively wide beamwidth of the low frequency (UHF) AEW radar. Ducting conditions have extended the radar range considerably and Multiple Time Around Echoes (MTAE) appear from very far off land and mountains appear as clutter on the radar display. The effect of this long range land return is very pronounced when the aircraft is within the surface duct. For an elevated layer the aircraft experiences much clutter when it is in and above the layer and experiences normal coverage when it is below the elevated layer.

4. ASW Aircraft Operations

As discussed above, the presence of anomalous propagation conditions may allow a number of combinations of emitter and target position between which the propagation path does not exist although the positions are within normal range of each other. Such conditions may preclude an airborne ASW system's effective performance. The same conditions can be used by the OTC to his advantage if the knowledge of their existence and their effects are known. This would greatly assist in tracking, control and communicating with the ASW aircraft. Presence of ducting conditions may enable the ASW helicopter to maintain a sonar contact and communicate with the control ship at the same time while operating beyond line of sight ranges. Otherwise it may have to break dip in order to communicate to the ship and thus loose sonar contact.

The environmental conditions can and sometimes do change significantly over a period of a few hours. This makes the availability of current real time refractive information all the more important. An ASW aircraft constrained by its mission will not be able to fly at very high altitudes to overcome the effects of anomalous propagation conditions. At lower altitudes it is bound to be affected by the layers. During sonobuoy processing unsuitable altitude and range from the sonobuoy field, in presence of ducting conditions, may prevent the VHF sonobouy signals from reaching the aircraft. Furthermore the UHF communication between ship and aircraft may cause difficulty in tracking and controlling the ASW aircraft.

As mentioned earlier, the Arabian Sea is a relatively data poor area which necessitate some means of obtaining the real time information about the refractive structure of the atmosphere for effective operations at sea. An AMR fitted onboard an ASW aircraft will increase the effectiveness of its mission and can provide the useful refractive information to ships and aircraft which otherwise would not be available at sea.

The Pakistan Navy is expected to use its P-3C in multipurpose role in addition to its primary ASW role. In the absence of a dedicated AEW platform, a P-3C may also be used for general reconnaissance and ESM missions. With HARPOON firing capability, one of its missions can be as an Anti

Surface Vehicle (ASV) platform. When in ASV configuration, it can be a lethal weapon for enemy surface ships and is capable of providing third party targeting and carrying out multidimensional attack on enemy forces.

5. Over The Horizon Targeting (OTHT)

Over the horizon missile targeting in the absence of a third party targeting platform is restricted due to the radar LOS constraints. A submarine equipped with subsurface-to-surface missile can use the ESM intercept information from a surface emitter which also happens to be within the evaporation or the surface based duct, to launch its OTH targeting weapons such as EXOCET or HARPOON. In the absence of ducting, the submarine is usually dependent upon third party targeting information.

Extended ESM detection ranges for surface radars can be utilized by surface ships to launch their surface-to-surface missiles. Visualize a scenario where intelligence sources report several enemy ships operating in a certain area. A P-3C, capable of firing HARPOON, is tasked to conduct a co-ordinated attack with an ASV helo from a ship. One way to achieve a surprise attack is to close the enemy silently, relying heavily on the ESM intercept of the enemy radar emissions. An Airborne Microwave Refractometer (AMR) onboard P-3C indicates to the aircraft commander the positions of ducts and helps him achieve ESM intercepts long before it can

be detected by the enemy long range early warning radar. The aircraft can take two or three intercept bearings to localize the emitter. In the final phase of the attack the P-3C can advise the helo to close the enemy at such an altitude so as to remain undetected within enemy's 'radar hole' till the weapon release point. Both the aircraft can launch weapons from different directions to attain maximum effectiveness against enemy anti-missile defenses efforts. A discussion on AMR and its operation continues in next chapter.

6. Anti-Radiation Missiles (ARM)

Anti-radiation missiles have shown excellent prospects during the last decade to be a favorite tactical weapon of the future. These are missiles which home on the adversary's EM radiations. The nature and operation of early warning radars generally make them the most suitable target for extended range, selective attack. ARM can tactically be used in two different ways. First in the Suppression of Enemy Defence (SEAD) as an offensive tactic to reduce enemy defensive capabilities, thereby increasing effectiveness of friendly forces similar to the way like active ECM or jamming degrade the ability of enemy sensors.

In its second, which is a defensive, role an ARM equipped aircraft reacts to engagement by an imminent threat radar (such as surface-to-air missile or anti-aircraft gun fire control radar) by rapidly engaging the threat radar with

the ARM for own force protection. The presence of refractive and subrefractive layers in the atmosphere which respectively enhance and inhibit propagation of RF energy renders the anti radiation missile a potentially useful device that could enhance the tactical mission of the EW aircraft suppression of enemy defence from extended ranges. They can be launched pre-emptively from comparatively greater distances to shut down the enemy's active sensors.

C. HARMFUL EFFECTS OF DUCTING

1. Ducting Creates Holes

Ducting is not always a desirable phenomena to the forces at sea. Although it can provide long interception ranges, at times it also proves to be disadvantageous by creating nulls or radar holes in the radar coverage and by providing extended clutter reception. Since some energy goes in a non-intended direction, the power projected in the desired direction is reduced considerably. Therefore on one hand you may achieve long detection ranges of targets and ESM intercepts but on the other hand the potential problems of radar holes and height errors can become seriously detrimental.

Elevated ducts can cause the shipborne radar energy to be severely bent downwards whereby higher elevation target may be missed and a ray diverted from its intended direction may detect a target. This target will be indicated by the radar

system to be along the originally intended direction but at the wrong height. This will cause 'Height Error' as depicted in Figure 9 in Chapter II. In Figure 20, an elevated duct is shown to prevent an AEW radar from spotting an approaching a/c. The other side of the diagram shows an elevated duct masking the approaching plane in the radar hole from shipboard radar [Ref. 14:p. 68].

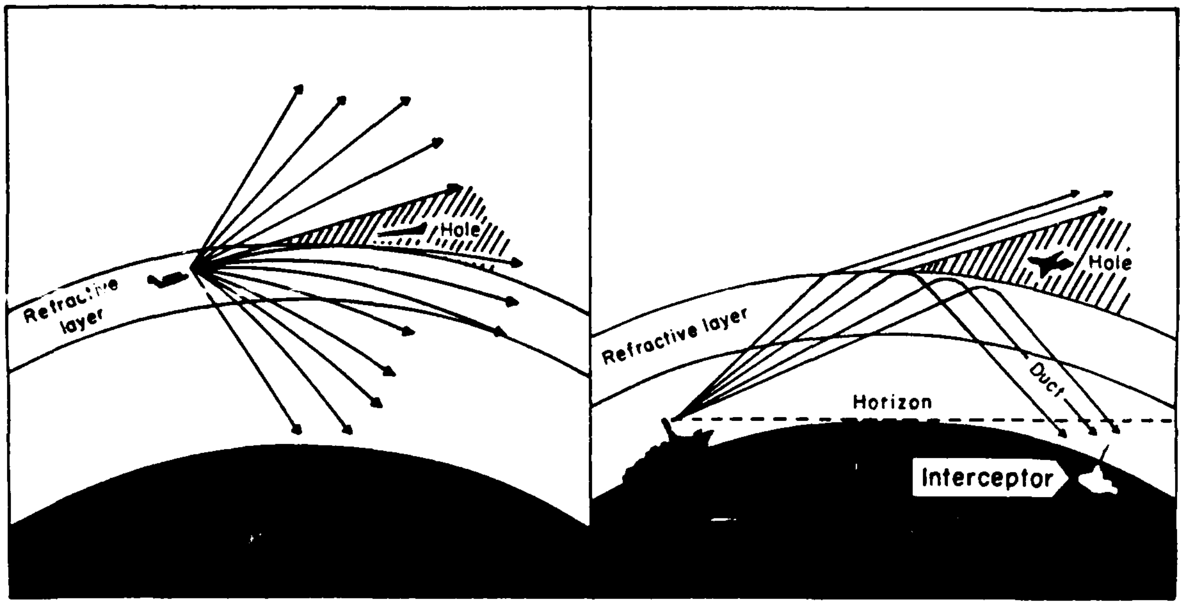


Figure 20 An elevated duct prevents an AEW aircraft and a ship from spotting an approaching aircraft

2. Ducting Enhances Sea Clutter Effects

The phenomena of surface based or evaporation ducting can increase the sea clutter return that can degrade the radar performance. Beach [Ref. 15:p. 83] describes how the ducting conditions can extend the horizontal extent of the sea clutter and can make it more difficult to discriminate smaller targets just above the sea surface from background noise. This can

result in intermittent detection of actual and false targets induced by the atmosphere. The intensity of the returned sea clutter will depend on the roughness of the sea surface and the strength of the duct.

Typical propagation paths in surface based duct can result in a number of discrete range intervals of high sea clutter which can degrade the radar display. These discrete intervals are normally independent of azimuth angles that can appear as sea clutter rings centered on the PPI display. Evaporation duct on the other hand can result in continuous, enhanced clutter return with range. Airborne radars are also affected by sea clutter and increased clutter due to from ducting conditions during anti-surface operations that can degrade their performance considerably. Sea clutter and nearby land clutter gets enhanced often to mask the targets and cause confusion to the operators. The fact is further illustrated in figures in Appendix A.

V. AIRBORNE MICROWAVE REFRACTOMETER (AMR)

One of the most accurate method of assessment of the refractive structure of the atmosphere is the use of airborne microwave refractometers. Although, as described, the strength of the duct depends on the temperature and the humidity gradients the AMR measures the refractivity directly. The knowledge of the refractive conditions is required in order to predict the performance of weapon and surveillance systems. Abnormal behavior of the radar beam depends on the strength of the duct and the angle of incidence of rays with respect to the duct. The strength of the duct depends on the temperature gradient and the humidity. The ability of the AMR to detect presence of ducting layers and collect refractive data makes it a device which could enhance the effectiveness and tactical mission of the AEW aircraft. The data collected by the AMR can be used by the force commanders either offensively or defensively. This can be used to assist in positioning of the ESM and ECM assets, shipboard and airborne radars, and planning aircraft strikes at altitudes that minimize likelihood of detection by radar.

Most of the information used in this thesis in describing the operation of AMR has been obtained through material provided by Naval Avionic Center (NAC) [Ref. 16] and as a result of a visit to NAC.

A. SYSTEM DESCRIPTION AND OPERATION

The US Navy currently uses AN/AMH-3 AMR onboard its E-2C aircraft and a modified version is planned to be fitted on EA-6B's. The AN/AMH-3 is an advanced meteorological system for determining the refractive index of air as a function of altitude of the airplane. The AN/AMH-3 set consists of three basic components. A simplified block diagram of the system is shown in Figure 21.

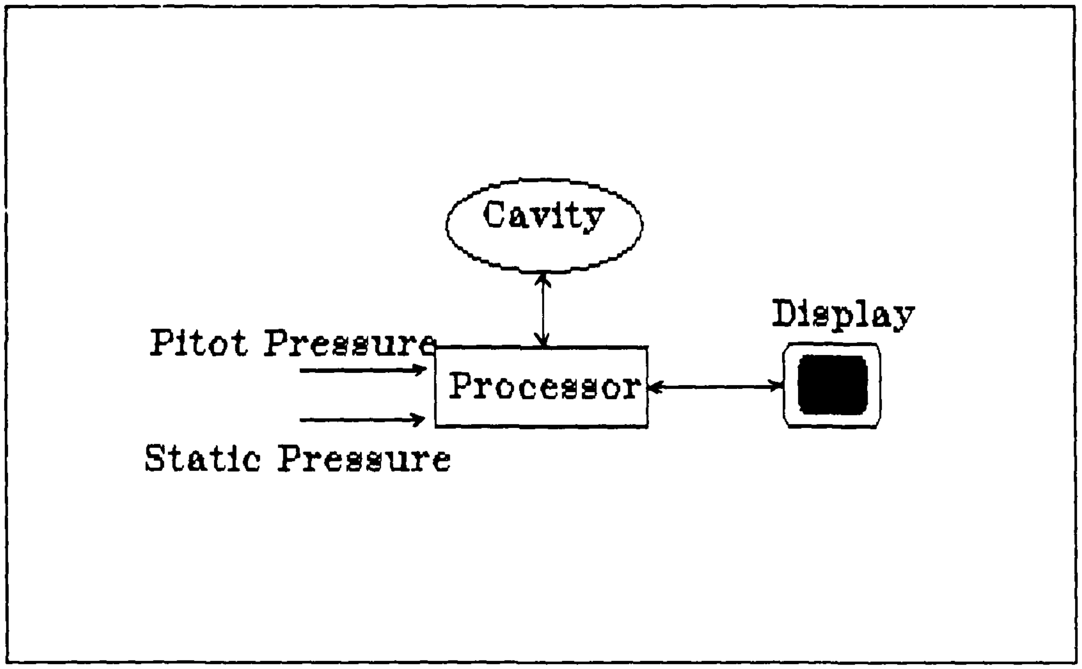


Figure 21 Block diagram of an AMR

The system samples the atmosphere via a tuned cavity assembly which contains a sampling cavity whose resonant frequency is directly a function of the refractive index of the atmosphere passing through it at any time. The cavity is housed in an aerodynamic foil or faring with a temperature

sensor and the required hardware for conveying the microwave RF signal through the cavity to the detector hardware mounted on the top. In the recorder-processor unit processing of the temperature, pressure, and refractivity data is carried out in conjunction with direct analog input of the pitot and static pressures. The data is digitized and serialized to be fed into the cassette recorder for storage and to the microprocessor controlled firmware that stores and further processes the data for use on the LCD panel in the control-indicator.

The control indicator provides the control source for the set and the real time refractive data via a liquid crystal display panel. The AMR provides the real time and recorded assessment of the meteorological profile along the airplane flight path at various altitudes. It locates and identifies those super-refractive or subrefractive layers that are considered to affect the performance of the surveillance and communication systems. The set also provide the distance measured along the tangent line from the aircraft to the refractive layer being assessed.

The AMR samples the atmosphere to determine the refractivity and also records it for post-flight processing. During the processing the modified refractivity, **M**, is calculated as a function of altitude to determine the vertical extent of the duct. The raw real time recorded data consists of static pressure, pitot pressure, temperature, and

refractive index in N-units and can further be processed by IREPS.

B. DESCRIPTION OF DISPLAYS

On the control panel the Liquid Crystal Display (LCD) has been divided into the right and left hand displays. The control indicator also contains seven control switches for various functions of the set. The right hand panel displays approximate locations of all declared layers. Ducting layer strengths are also indicated on the same display.

Figure 22 shows the display in the initial display test mode. The vertical numerals indicate the altitude range from zero to 30 kft. A diamond placed in between any two altitudes indicate the presence of at least one ducting layer within that region. AMR declares a super refracting or ducting layer when during the aircraft ascent the refractivity decreases by more than 48 N-units/kft for at least 200 ft. If the duct thickness is greater than 500 ft, AMR considers it a strong duct and if it is from 200 ft to 500 ft, it is a weak one.

Any duct with a thickness of less than 200 ft is considered too weak to be declared. A plus sign on left of diamond indicate that it is a strong duct and its absence indicate a weak duct. A '1' on the left of plus sign shows that the declared duct is the strongest. Presence of a subrefractive layer is indicated by a down pointing triangle placed to the right of any two altitudes. The AMR declares

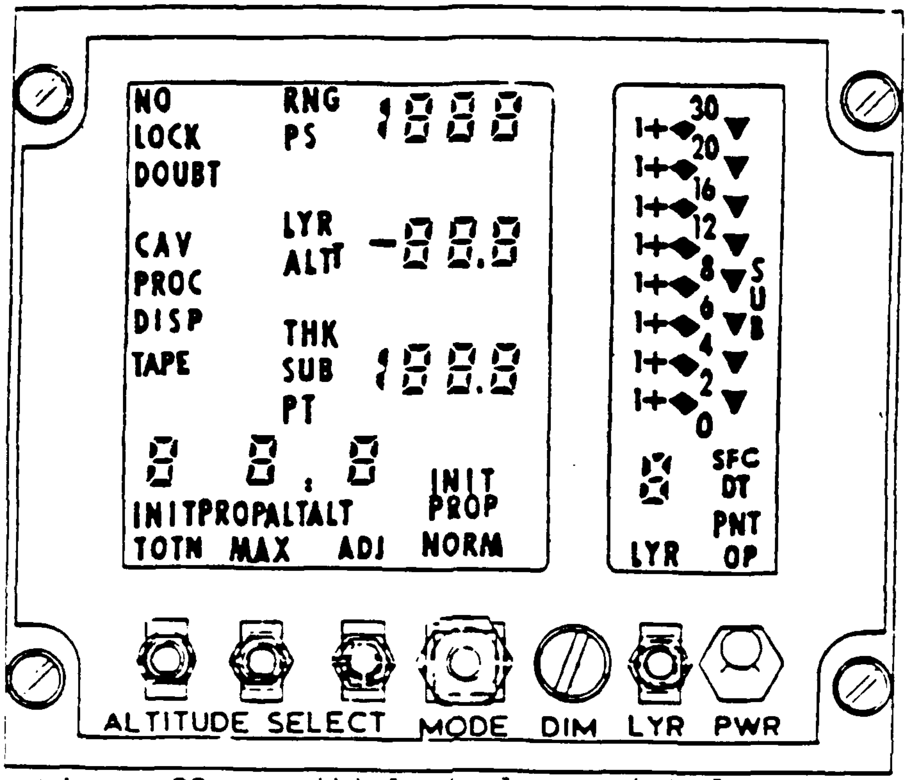


Figure 22 Initial Display Test Mode.

such a layer at an altitude where the refractivity begins to increase at a minimum rate of 3.7 N-unit for 100 ft.

In addition to the down pointing triangle the vertical letter 'SUB' will also appear to the right of it on the display. A surface duct is displayed when the thickness of the lowest declared duct is equal to its altitude above sea level and is at least 200 ft. The AMR displays the bottom diamond and, in addition, vertical letter 'SFC' will also be displayed to indicate the presence of surface duct. An elevated duct will be displayed in a similar way but the letter 'SFC' will not appear on the display in this case. A number at the bottom

left corner of the right hand display indicates the number of the layer currently being assessed on the left display panel.

The left hand panel displays the status of cavity/sweep oscillator circuit, error diagnosis, tape indicator, different modes of the set, altitude of selected layer, and thickness of the selected duct. It also displays a horizontal range 'RNG' reading in nautical miles to the indicated layer. The range RNG is the distance measured along the tangent line from the aircraft to the refractive layer being assessed. This layer must be below the aircraft. The RNG reading appear in the normal and proposed altitude modes.

During the pre-flight operation the set is energized and tested for pre-flight checks. Initial altitude is set corresponding to the present altitude above sea level. During these checks, static pressure and pitot pressure readings are confirmed to agree within +-10 mb. N-unit readings should lie between 250 to 450 range and it should not vary by more than several N units over a 15 to 30 seconds time period. On completion of these checks the set is switched to normal operation mode for the flight.

C. FLIGHT OPERATION

During its flight the AMR may pass through a number of different layers and will declare them accordingly. In general refractive conditions are found with greater frequencies over warm oceans. Arabian Sea with its warm climate has a greater

occurrence of ducting phenomena as discussed in Chapter III. It is considered that the inclusion of an AMR onboard a maritime patrol aircraft can considerably enhance its mission effectiveness. In its proposed altitude mode the AMR is used to determine how high the aircraft must fly above a given layer to extend the range to a desired minimum value. An important advantage is gained when the data collected by the tape recorder is analyzed with IREPS. Some of the possible scenarios are discussed below where the AMR detects and displays refractive layers and the situation is analyzed with IREPS coverage displays.

1. Elevated Duct at 8.0 kft

Figure B.1 shows the IREPS propagation conditions summary for an elevated duct at 8.0 kft. Figure B.2 indicates the aircraft altitude at 5.0 kft. AMR declares no layer. The range RNG reading of 82 nmi is to the radar horizon. The LYR ALT is the altitude that was initialized before the take off. As the aircraft increases altitude the RNG reading keeps increasing but the AMR does not declare any layer till the aircraft is at an altitude of 7.9 kft.

As shown in Figure B.3, RNG reading " d d d " indicates that the aircraft is within a ducting layer. A diamond on the right hand display indicates the presence of duct in 6.0 kft to 8.0 kft region. The display indicates the layer altitude of 7.9 kft and the layer thickness so far to be

0.2 kft. When the aircraft is within the duct the radar energy can travel long distances for detection of targets within the duct but at the same time radar holes also appear above the duct.

Figure B.4 indicates aircraft altitude to be 9.0 kft. RNG reading of 36 nmi is the range to the declared ducting layer. LYR ALT indicates the top of the ducting layer to be at 8.0 kft. Total layer thickness is now indicated to be 0.3 kft. At this position not much of energy is being trapped inside the duct but we still experience a radar hole. As the aircraft gains altitude the display remains the same except that the RNG readings keep increasing. The effect of this elevated layer and the radar hole keep diminishing as the aircraft increases its altitude above the duct. In this case the radar hole completely disappears at an altitude of 25.0 kft as shown in Figure B.5.

2. Elevated Subrefractive Layer at 16.0 kft

Figure B.6 shows the propagation condition summary for an elevated subrefractive layer at 16.0 kft. The AMR does not declare any layer when it is at 15.0 kft and displays the RNG reading to be the range to horizon and IREPS indicate normal radar coverage. Figure B.7 indicates the aircraft to be at 17.0 kft. A triangle placed between the 12-16 kft region indicates the presence of a subrefractive layer in that region. The layer altitude is shown to be at 16.0 kft with a

range of 36 nmi to the subrefractive layer. At altitudes sufficiently high above the subrefractive layer the effects of the layer are negligible as shown in Figure B.8.

3. Surface Duct

Figure B.9 display the propagation condition summary for a surface based duct at 800 ft. Figure B.10 shows the aircraft to be at 1.0 kft. A diamond in the right-hand display indicates duct in the lowest altitude region with letter SFC indicating it to be a surface duct. The range to the top of the surface duct or to the radar hole at current altitude is 16 nmi. The layer altitude and the duct thickness is indicated to be 0.8 kft, confirming that it is a surface duct. At higher altitudes the range to the duct top continue increasing. Excessive radar clutter is also seen in some directions. Figure B.11 shows the IREPS coverage display when the radar is at 500 ft. Enhanced surface detection is caused by surface propagation beyond line of sight within the surface duct.

VI. SUMMARY AND RECOMMENDATIONS

The effects of the atmosphere on EM propagation have been long observed and recognized. Operational communicators have realized the importance of applying the atmospheric effects to selecting frequencies for ship-shore and broadcast circuits. It is an established fact that reliable communication cannot be maintained without an intelligent choice of frequency for time of the day, which is the case for HF spectrum use as a major form of Naval communication. UHF communications and radar are additional applications greatly influenced by the environmental and refractive effects. As shown, certain atmospheric conditions can cause the radio energy to propagate much different from the standard propagation. Predictions of such conditions can assist a commander at sea in a variety of ways.

The effects of atmospheric refractive structure on electromagnetic propagation and the tactical implications have been discussed. Subrefractive layers cause radar waves to bend away from the earth and ground coverage of the radar is decreased. Super-refractive layers bend radar waves towards the ground to travel longer distances. An exceptional case of super-refractive condition cause ducting to take place where energy is trapped in the duct and abnormally long ranges are obtained.

IREPS and EREPS are two commonly used PC-compatible software systems used for assessing the electromagnetic wave propagation effects of the lower atmosphere on EW, radar, and communication systems. The atmospheric parameters determined by balloon-borne radiosonde, or from the Airborne Microwave Refractometer are fed as input parameters to these programs and the outputs are easily displayed and interpreted. Some of the sample products of EREPS are shown in Appendix C. IREPS and EREPS concepts have been briefly described to highlight an important role which they play in providing useful information about sensor performance. It is recommended that these concepts be incorporated into the training program of Pakistan Navy personnel to enhance awareness about the impact of environment on the equipment performance. This will enable them to use their sensors in a better and intelligent way.

The AMR provides real time information in flight and is proposed for integration in the Pakistan Navy P-3C because of this. It does so by sampling the air in a cavity and calculating the index of refraction directly as the aircraft gains altitude. Such information can be either linked or transmitted to ships at sea if they are unable to launch their radiosonde for some reason. The knowledge of refractive conditions enables the force commander at sea to position his ESM and ECM assets, stationing of Combat Air Patrol (CAP) aircraft, planning of strike flight profiles, selecting an EMCON plan, and better use of ECM.

E-2C aircraft of the US Navy and some other countries like Singapore, Egypt, Japan, and Israel have been using the AMR for some time, and as far as the application and usefulness of AMR for the AEW aircraft is concerned, it is assessed as very useful for this mission. It is particularly useful when the mission is to detect and provide early warning of airborne threats. Given the position of elevated ducts, considerable long range detection and interception can be accomplished by flying the AEW aircraft within the duct if it is known that the target is in the duct, which may be hard to predict. For other high altitude targets, the AEW aircraft can be positioned below the elevated refractive layer to avoid radar holes in the coverage. For early warning of surface targets, the aircraft can be flown as high as possible to extend the radar coverage to longer distances. Various tactics and guidelines can be learned from exercises.

The E-2C can perform its mission without an AMR as designed, but the AMR increases its mission effectiveness greatly, and although not 'Mission Essential', it is considered an important 'Mission Enhancer' for the E-2C aircraft. In the same way, or perhaps more since surface ducts are more predictable, it is possibly more mission essential for a dedicated ASW aircraft. Having considered some of the aspects for an ASW aircraft mission where the knowledge of refractive conditions typically enhances its *mission* capabilities, it is considered to be a useful piece of

equipment for use in an ASW aircraft, and therefore proposed for installation on Pakistani P-3C aircraft. It is proposed that a near-term integration feasibility study be carried out for AMR installation on P-3C aircraft to provide enhanced mission effectiveness in the complete spectrum of mission assignments, primarily ASW, but also AEW, and anti surface warfare in which this capable aircraft is likely to employed.

APPENDIX A

AEW RADAR DISPLAY UNDER VARIOUS REFRACTIVE CONDITIONS

Figure A. 1 Aircraft 23,000 ft above a 1000 ft surface duct. Note the Multiple Time Around Echoes (MTAE) to East from land mass 680 NM away.

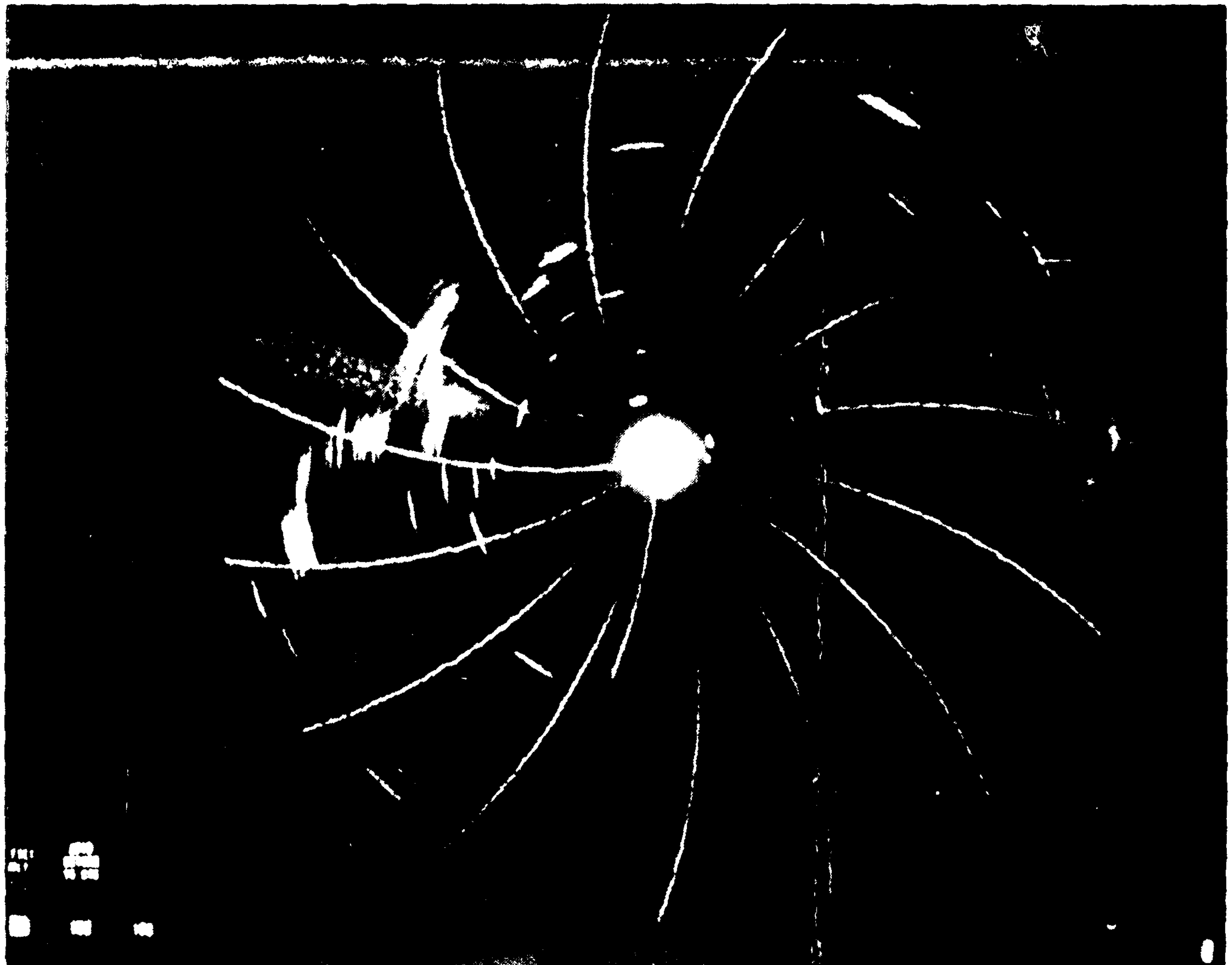


Figure A. 2   Aircraft is 2000 ft above a 1000 ft surface duct. Extended ranges are obtained up to 135 NM whereas the normal radar horizon range is 65 NM.

Figure A. 3 Aircraft is within the 1000 ft surface duct. All land area is beyond 30 NM radar horizon. All clutter to North and East is from land up to 720 NM away.

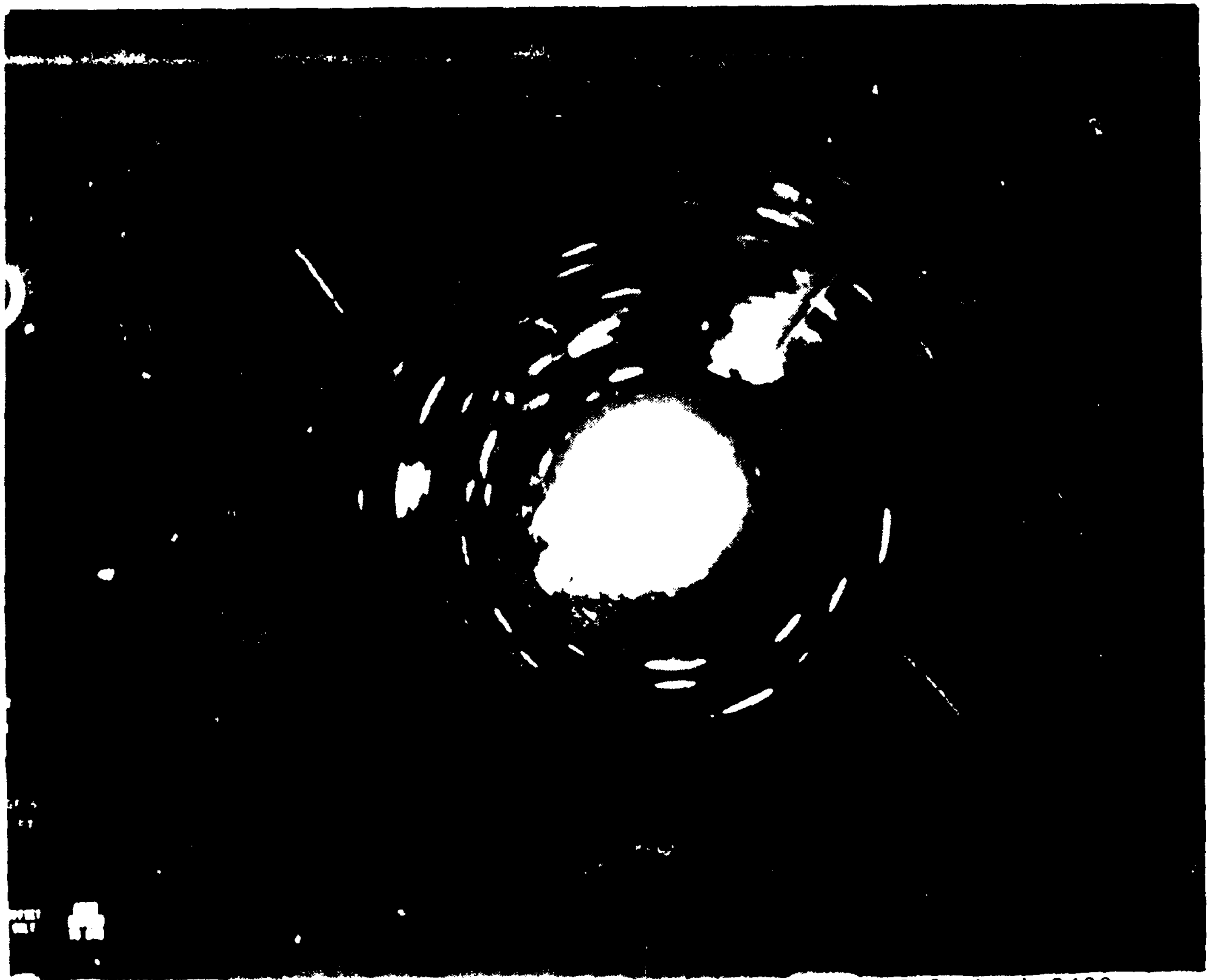


Figure A. 4   Aircraft is 8300 ft above an elevated duct at 2400-2950 ft. Multiple Time Around Echoes to West and North East are from land up to 650 NM away.

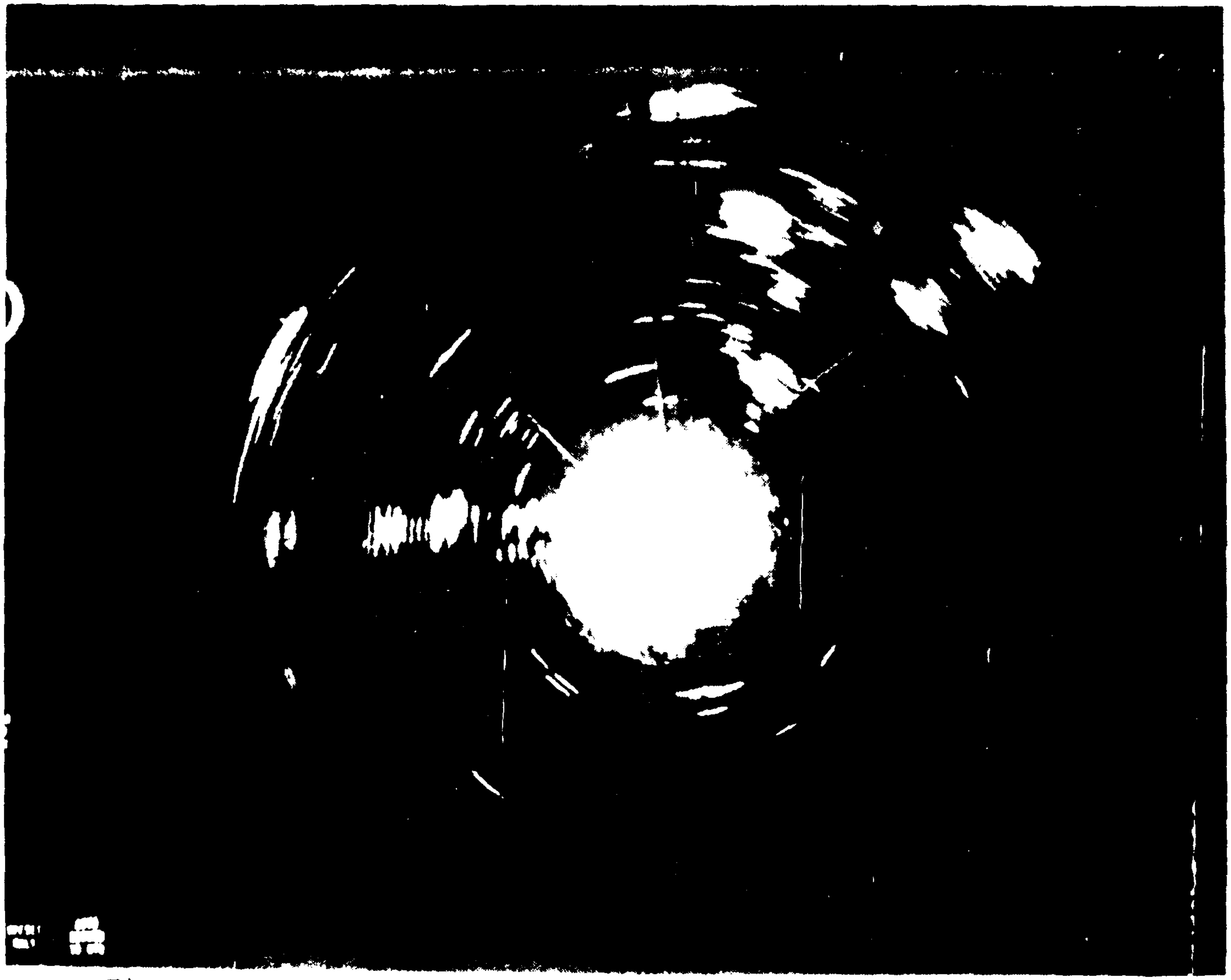


Figure A. 5 Aircraft is 3300 ft above an elevated duct at 2480-2950 ft. Note the increased clutter.

Figure A. 6 Aircraft is just above the elevated duct at 2480-2950 ft. Note the heavy MTAE's whereas the nearest land is 310 NM away. Clutter in North West is from land 710 NM away.

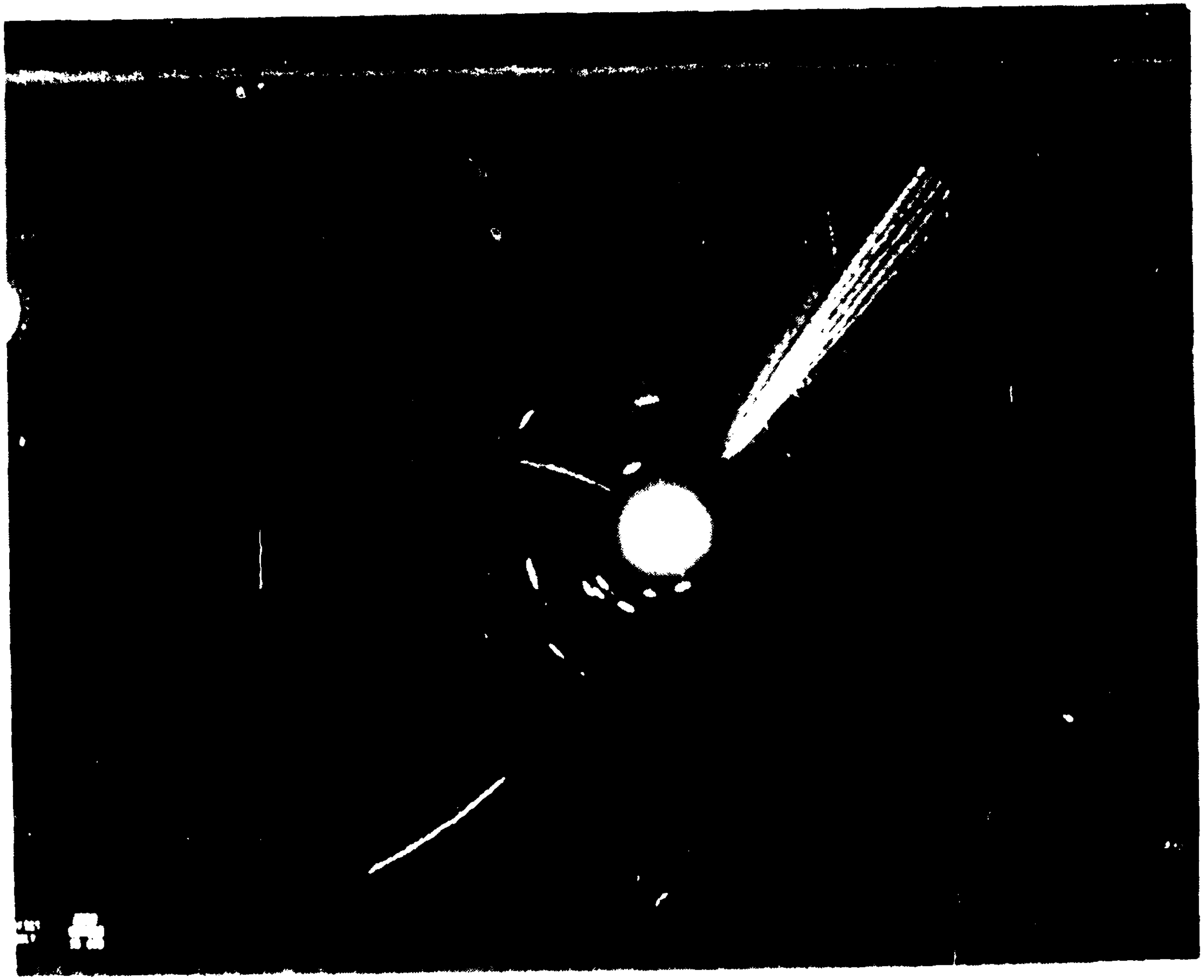


Figure A. 7   Aircraft is just below the elevated duct at 2480-2950 ft. Note that the clutter is only due to the fading as the aircraft descends.

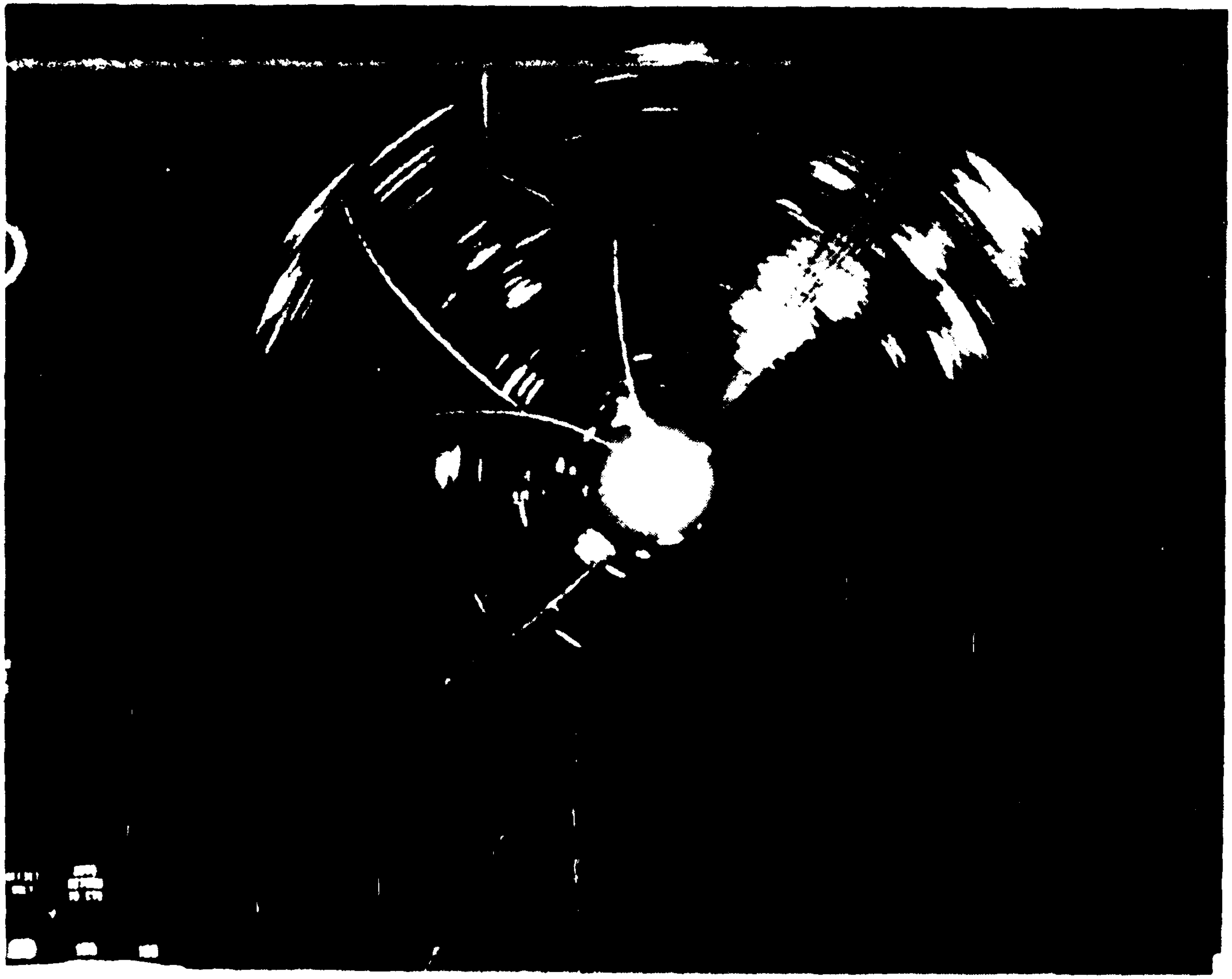


Figure A. 8   Aircraft is just below the duct at 2480-2950 ft. All MTAE's and clutter has disappeared giving normal surface detections. Radar horizon is 37 NM.

APPENDIX B

AMR DISPLAY AND IREPS COVERAGE DIAGRAMS

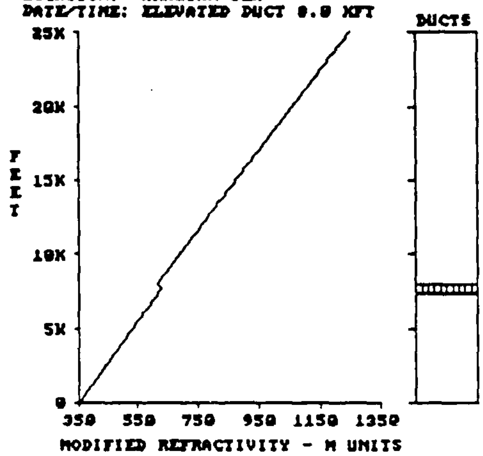
IREPS PC-1.02 **** PROPAGATION CONDITIONS SUMMARY ****

***** SURFACE-TO-SURFACE *****
EXTENDED RANGES ABOVE 6 GHZ

***** SURFACE-TO-AIR *****
NORMAL RANGES AT ALL ALTITUDES

***** AIR-TO-AIR *****
EXTENDED RANGES 7362 TO 8000 FT
POSSIBLE HOLES ABOVE 8000 FT

LOCATION: ARABIAN SEA
DATE/TIME: ELEVATED DUCT 8.0 KFT



*** ENVIRONMENTAL DATA LIST ***

LOCATION: ARABIAN SEA
DATE/TIME: ELEVATED DUCT 8.0 KFT
WIND SPEED= 12.0 KNOTS
HEIGHT OFFSET FROM MSL= .0 FT EVAPORATION DUCT HEIGHT= 13.0 M

LEVEL	FEET	N UNITS	N/KFT	M UNITS	CONDITION
1	.0	350.0	-37.1	350.0	NORMAL
2	7700.0	262.9	-292.0	631.3	TRAP
3	8000.0	236.2	-35.9	618.9	NORMAL
4	25000.0	50.0	----	1246.0	------

SURFACE REFRACTIVITY: 350.0 - - - SET SPS-48 TO 344.0

Figure B. 1

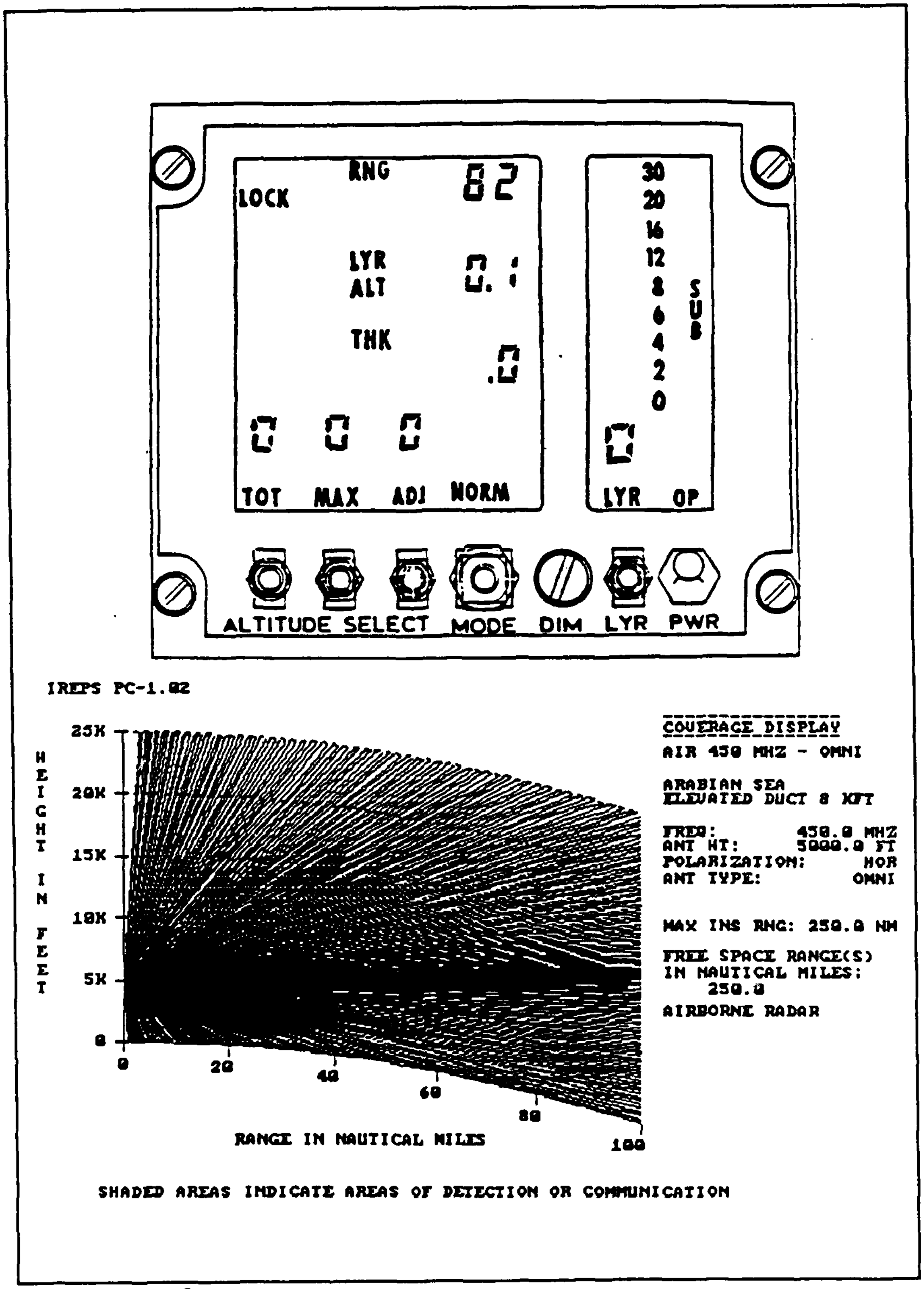
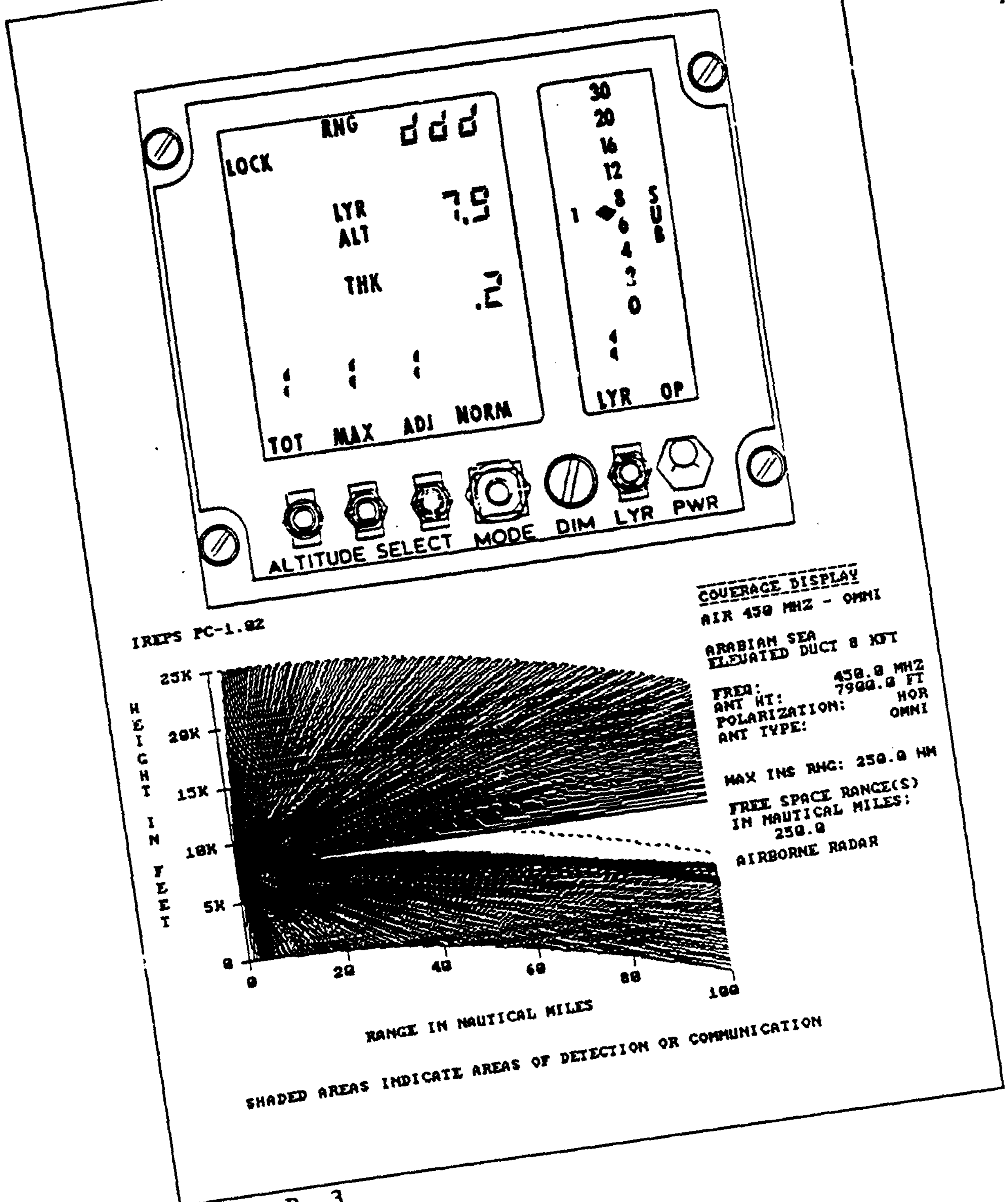

RNG
LOCK
LYR
ALT
THK
TOT
MAX
ADJ
NORM
30
20
16
12
8
6
4
2
0
SUB
LYR
OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
IREPS PC-1.02
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
ELEVATED DUCT 8 KFT
FREQ: 450.0 MHZ
ANT HT: 5000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
HEIGHT IN FEET
25K
20K
15K
10K
5K
0
RANGE IN NAUTICAL MILES
0
20
40
60
80
100
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 2



RNG
LOCK
LYR
ALT
7.9
THK
.2
TOT
MAX
ADJ
NORM
30
20
16
12
8
6
4
3
0
SUB
LYR
OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
IREPS PC-1.02
ARABIAN SEA
ELEVATED DUCT 8 KFT
FREQ: 450.0 MHZ
ANT HT: 7900.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
HEIGHT IN FEET
25K
20K
15K
10K
5K
0
0
20
40
60
80
100
RANGE IN NAUTICAL MILES
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 3

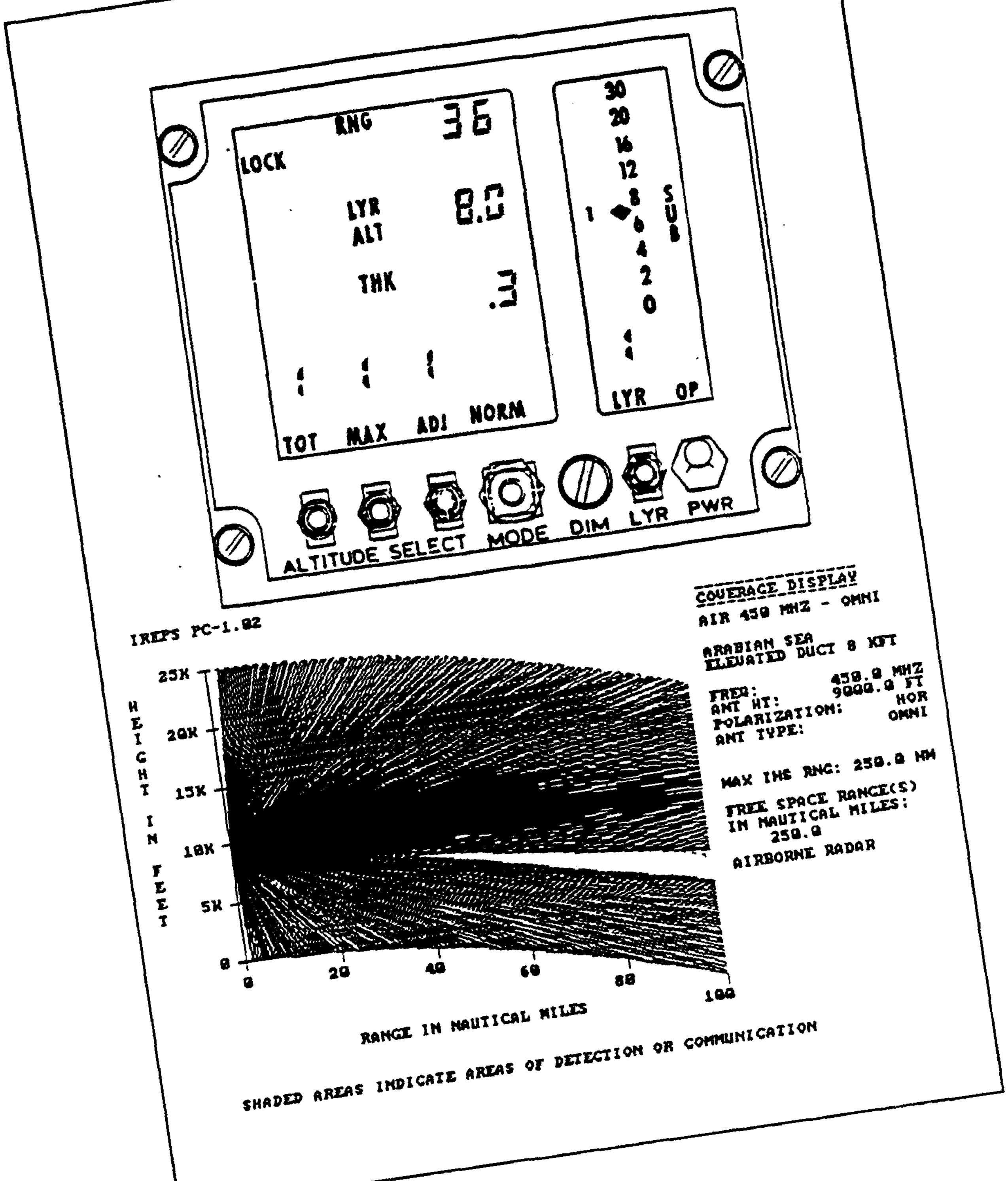

RNG
36
LOCK
LYR
ALT
8.0
THK
.3
TOT
MAX
ADJ
NORM
30
20
16
12
8
6
4
2
0
1
SUB
LYR
OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
IREPS PC-1.02
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
ELEVATED DUCT 8 KFT
FREQ: 450.0 MHZ
ANT HT: 9000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX IHS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
HEIGHT IN FEET
25K
20K
15K
10K
5K
0
0
20
40
60
80
100
RANGE IN NAUTICAL MILES
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 4

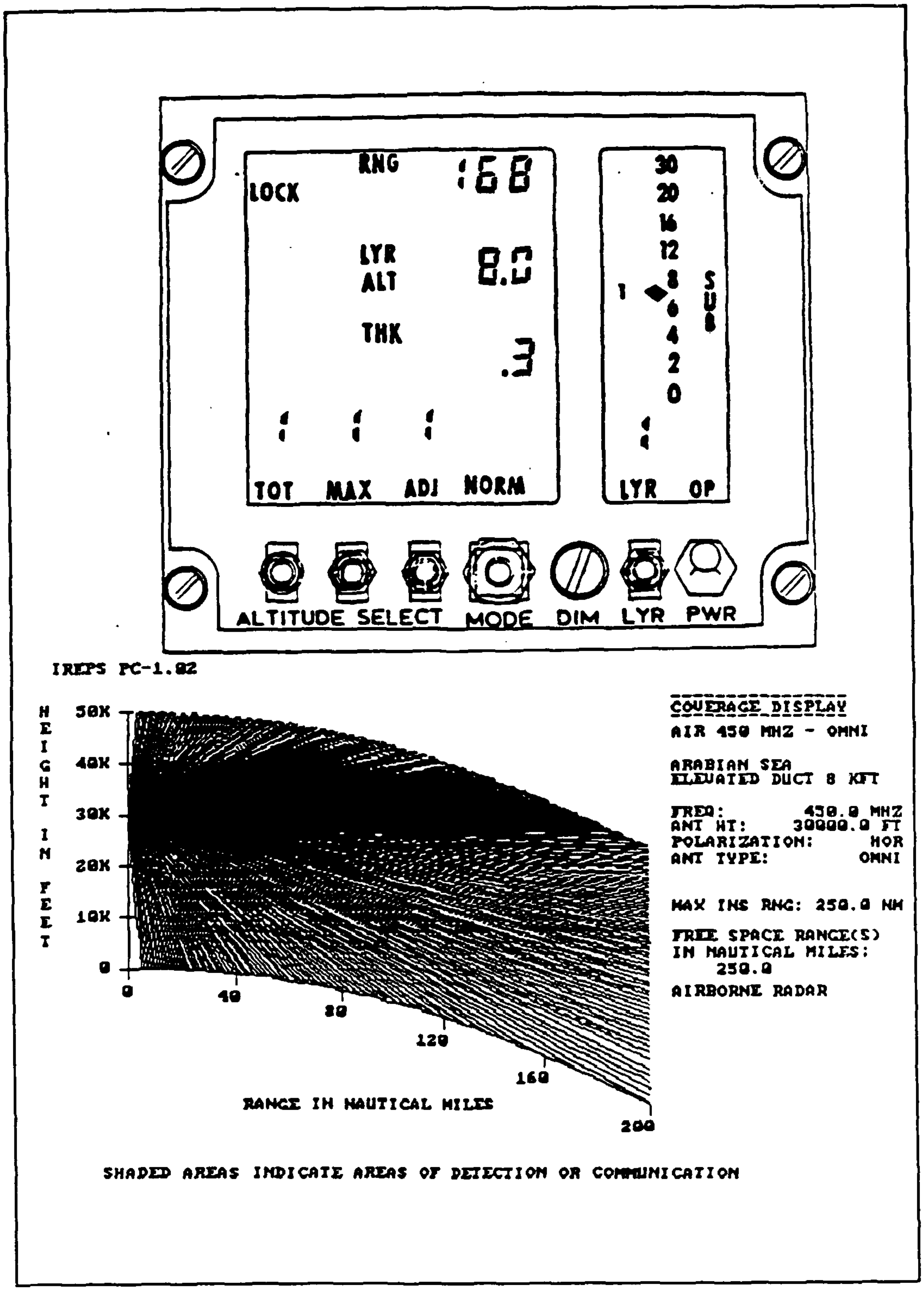

RNG
168
LOCK
LYR ALT
8.0
THK
.3
TOT MAX ADJ NORM
30
20
16
12
8
6
4
2
0
T
SUB
LYR OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
IREPS PC-1.02
HEIGHT IN FEET
50K
40K
30K
20K
10K
0
0
40
80
120
160
200
RANGE IN NAUTICAL MILES
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
ELEVATED DUCT 8 KFT
FREQ: 450.0 MHZ
ANT HT: 30000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S) IN NAUTICAL MILES: 250.0
AIRBORNE RADAR
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 5

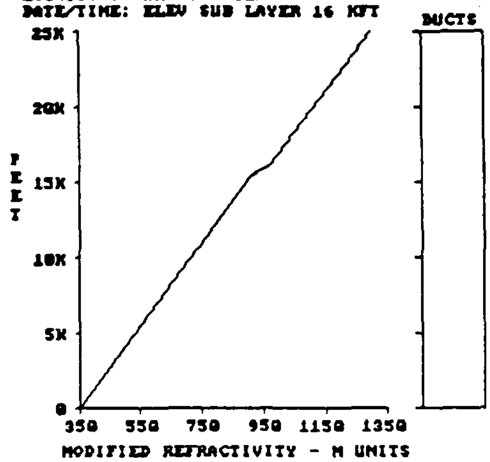
IREPS PC-1.02 **** PROPAGATION CONDITIONS SUMMARY ****

**** SURFACE-TO-SURFACE ****
EXTENDED RANGES ABOVE 6 GHZ

**** SURFACE-TO-AIR ****
NORMAL RANGES AT ALL ALTITUDES

**** AIR-TO-AIR ****
NORMAL RANGES AT ALL ALTITUDES

LOCATION: ARABIAN SEA
DATE/TIME: ELEV SUB LAYER 16 KFT



*** ENVIRONMENTAL DATA LIST ***

LOCATION: ARABIAN SEA
DATE/TIME: ELEV SUB LAYER 16 KFT
WIND SPEED= 12.0 KNOTS
HEIGHT OFFSET FROM MSL= .0 FT EVAPORATION DUCT HEIGHT= 13.0 M

LEVEL	FEET	N UNITS	N/KFT	M UNITS	CONDITION
1	.0	350.0	-37.1	350.0	NORMAL
2	15500.0	174.9	190.3	916.4	SUB
3	16000.0	203.8	-37.1	969.3	NORMAL
4	25000.0	102.2	----	1298.2	------

SURFACE REFRACTIVITY: 350.0 - - - SET SPS-48 TO 344.0

Figure B. 6

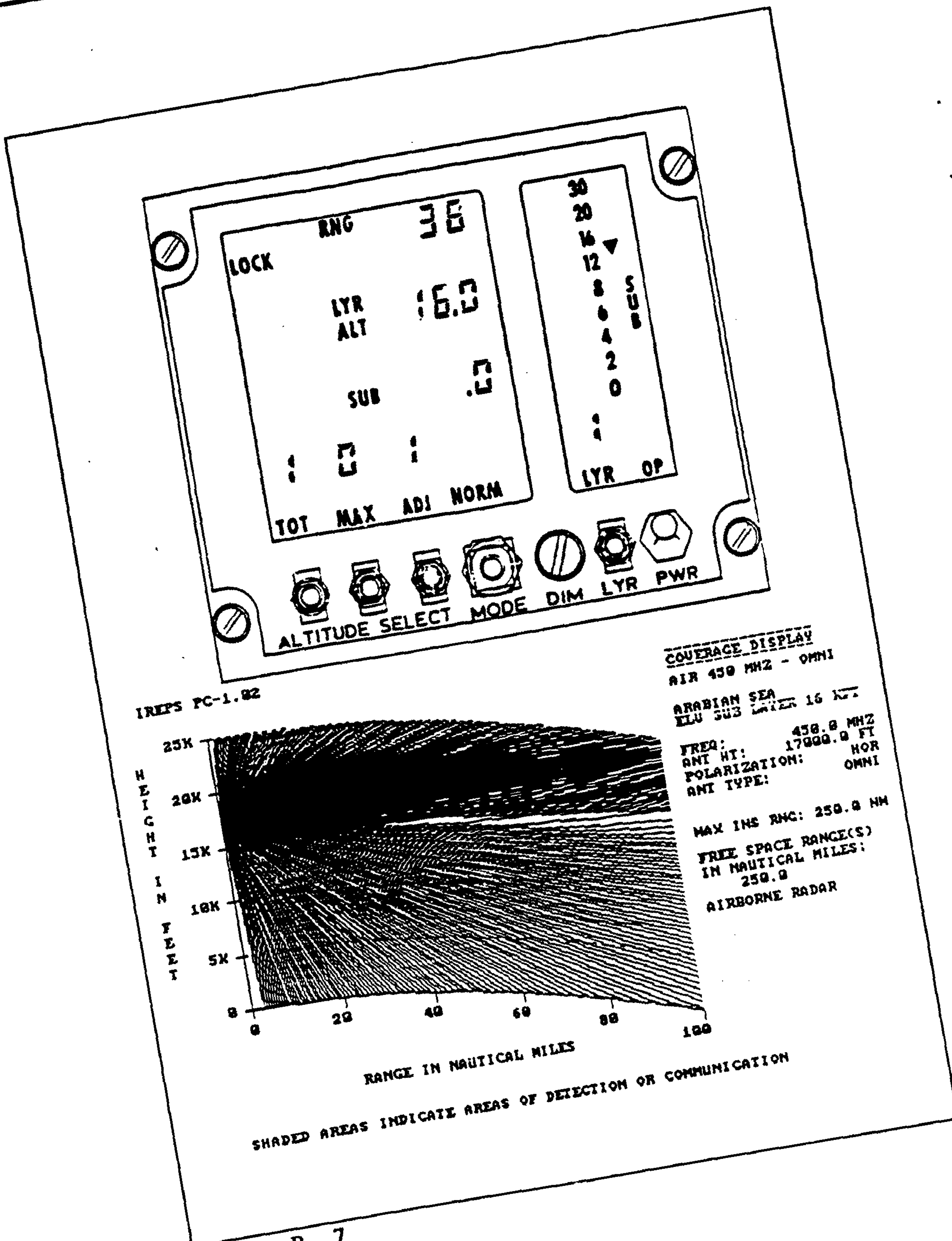

RNG 36
LOCK
LYR ALT 16.0
SUB .0
1 0 1
TOT MAX ADI NORM
30
20
16
12
8
6
4
2
0
SUB
LYR OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
IREPS PC-1.02
ARABIAN SEA
ELU SUB LAYER 16 KFT
FREQ: 450.0 MHZ
ANT HT: 17000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
25K
20K
15K
10K
5K
0
HEIGHT IN FEET
0
20
40
60
80
100
RANGE IN NAUTICAL MILES
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 7

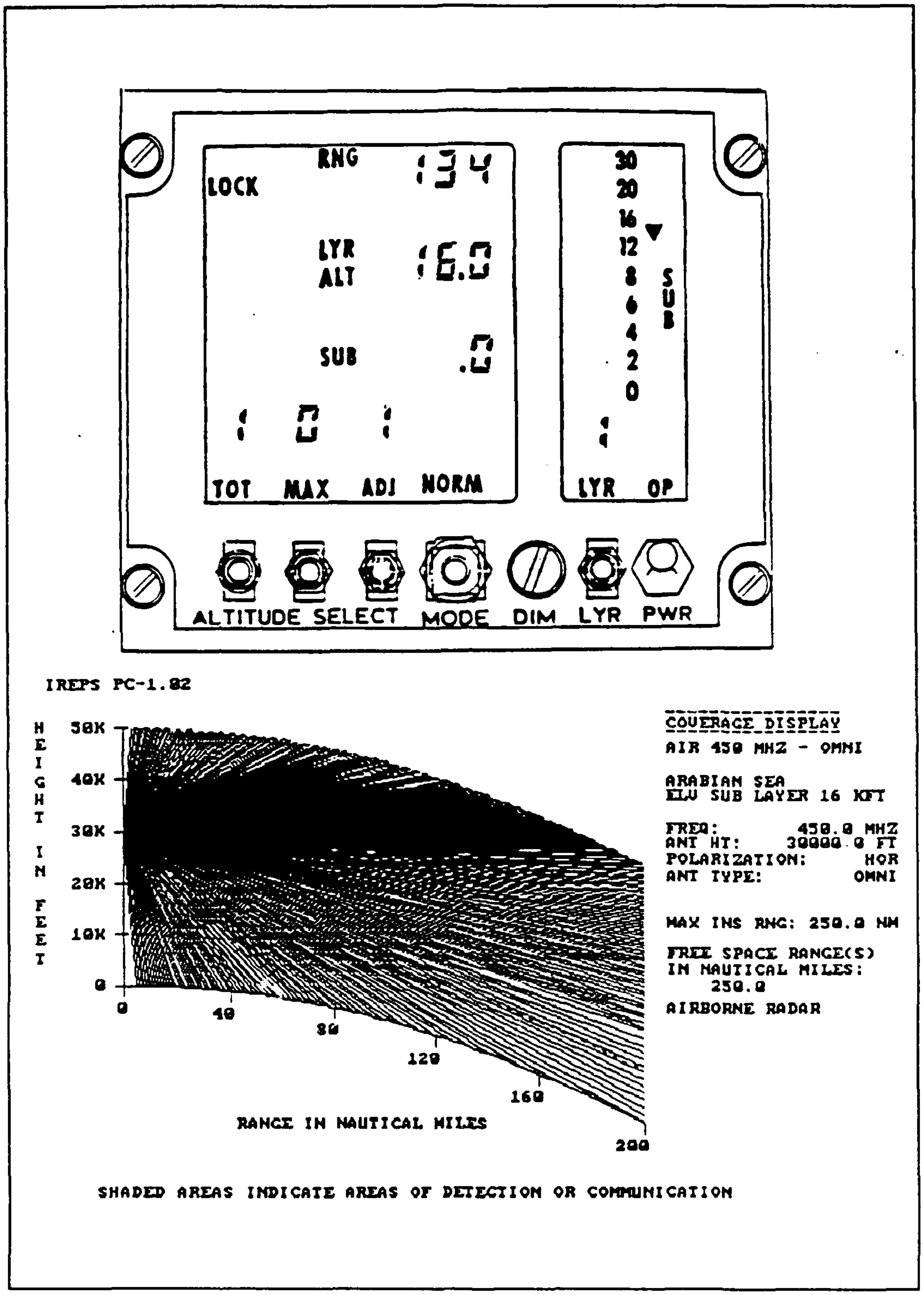

LOCK
RNG
134
LYR
ALT
16.0
SUB
.0
TOT
MAX
ADJ
NORM
30
20
16
12
8
6
4
2
0
SUB
LYR
OP
ALTITUDE SELECT
MODE
DIM
LYR
PWR
IREPS PC-1.02
HEIGHT IN FEET
50K
40K
30K
20K
10K
0
0
40
80
120
160
200
RANGE IN NAUTICAL MILES
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
ELV SUB LAYER 16 KFT
FREQ: 450.0 MHZ
ANT HT: 30000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 8

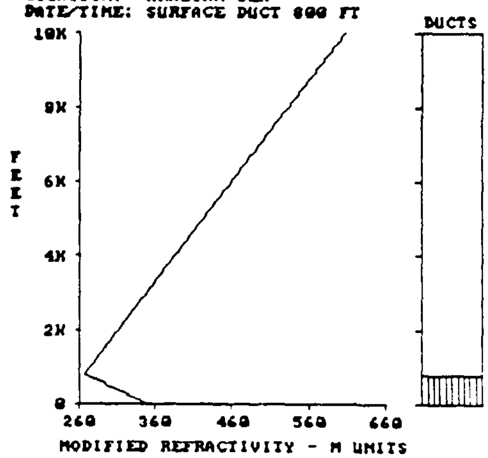
IREPS PC-1.02 *** PROPAGATION CONDITIONS SUMMARY ***

**** SURFACE-TO-SURFACE ****
EXTENDED RANGES AT ALL FREQUENCIES

**** SURFACE-TO-AIR ****
EXTENDED RANGES 0 TO 800 FT
POSSIBLE HOLES ABOVE 800 FT

**** AIR-TO-AIR ****
EXTENDED RANGES 0 TO 800 FT
POSSIBLE HOLES ABOVE 800 FT

LOCATION: ARABIAN SEA
DATE/TIME: SURFACE DUCT 800 FT



*** ENVIRONMENTAL DATA LIST ***

LOCATION: ARABIAN SEA
DATE/TIME: SURFACE DUCT 800 FT
WIND SPEED= 12.0 KNOTS
HEIGHT OFFSET FROM MSL= .0 FT EVAPORATION DUCT HEIGHT= 13.0 M

LEVEL	FEET	N UNITS	N/KFT	M UNITS	CONDITION
1	.0	350.0	-493.1	350.0	TRAP
2	800.0	229.8	-37.1	268.0	NORMAL
3	10000.0	125.8	----	604.3	------

SURFACE REFRACTIVITY: 350.0 - - - SET SPS-48 TO 344.0

Figure B. 9

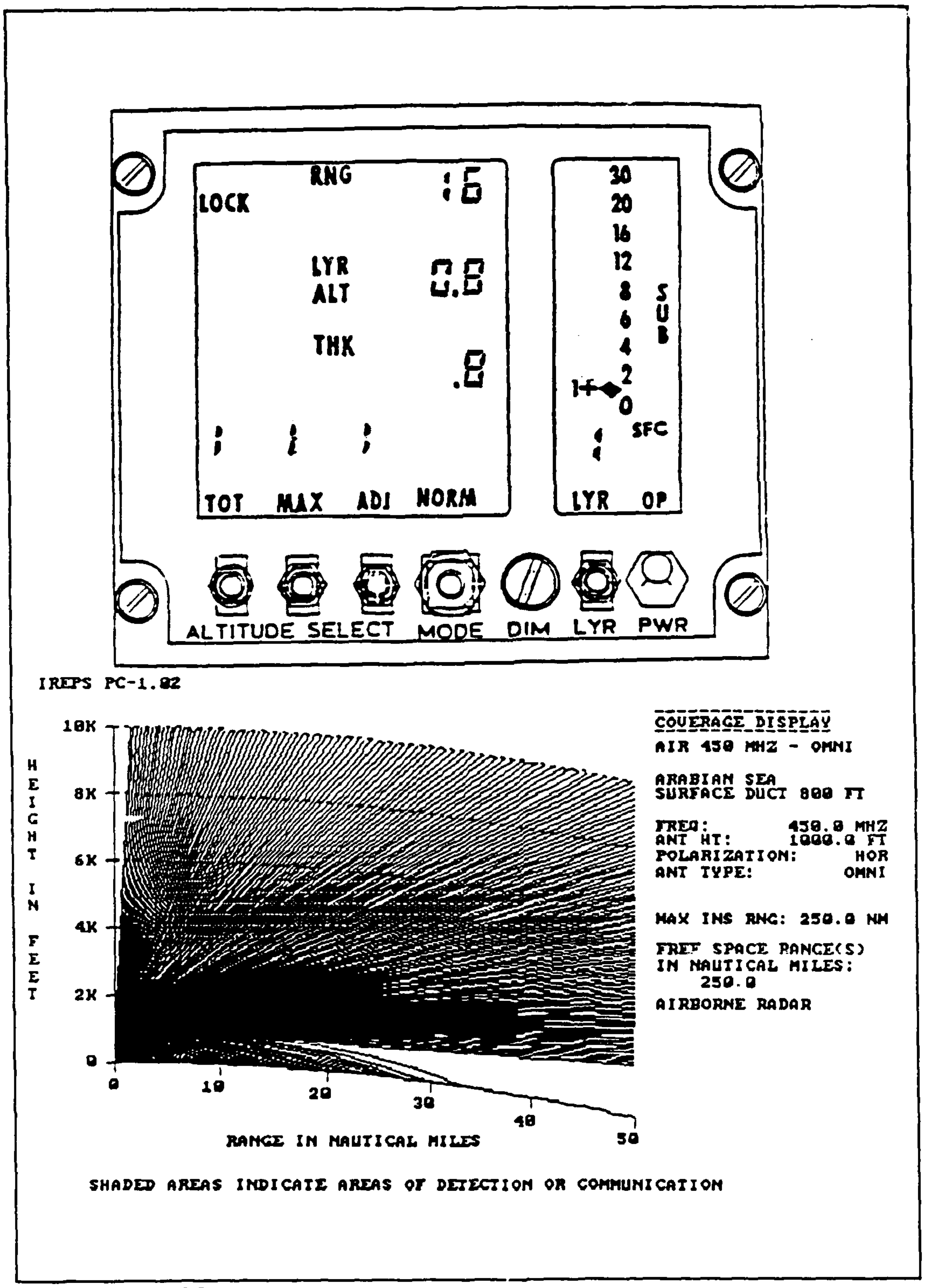

RNG
LOCK
LYR
ALT
THK
TOT MAX ADJ NORM
30
20
16
12
8
6
4
2
0
SUB
SFC
LYR OP
ALTITUDE SELECT MODE DIM LYR PWR
IREPS PC-1.02
COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
SURFACE DUCT 800 FT
FREQ: 450.0 MHZ
ANT HT: 1000.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
HEIGHT IN FEET
10K
8K
6K
4K
2K
0
0
10
20
30
40
50
RANGE IN NAUTICAL MILES
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 10

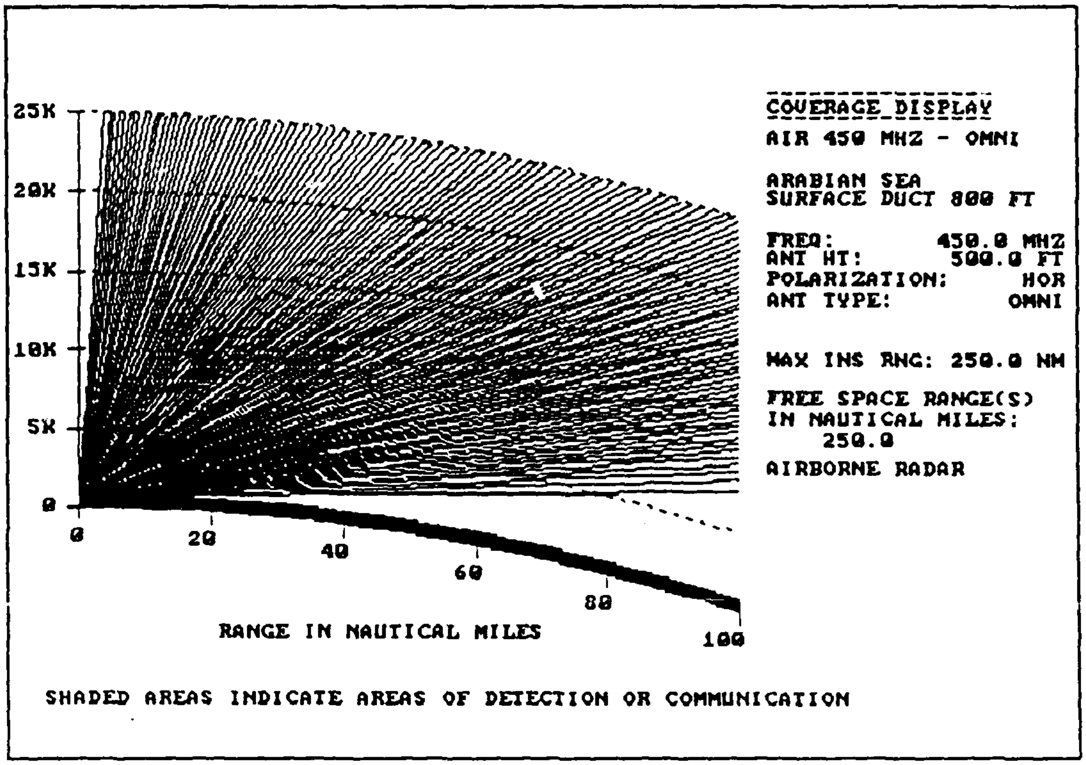

COVERAGE DISPLAY
AIR 450 MHZ - OMNI
ARABIAN SEA
SURFACE DUCT 800 FT
FREQ: 450.0 MHZ
ANT HT: 500.0 FT
POLARIZATION: HOR
ANT TYPE: OMNI
MAX INS RNG: 250.0 NM
FREE SPACE RANGE(S)
IN NAUTICAL MILES:
250.0
AIRBORNE RADAR
25K
20K
15K
10K
5K
0
0
20
40
60
80
100
RANGE IN NAUTICAL MILES
SHADED AREAS INDICATE AREAS OF DETECTION OR COMMUNICATION

Figure B. 11

APPENDIX C

SAMPLE PRODUCTS OF EREPS

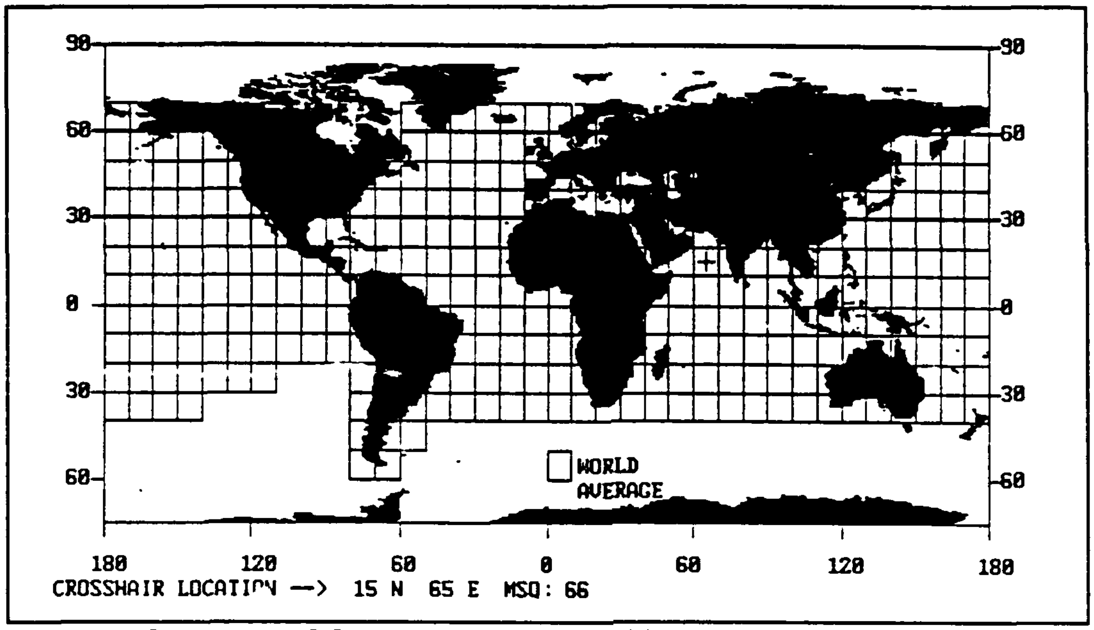


Figure 34 World map showing 293 marsden squares for which SDS provides the climatology.

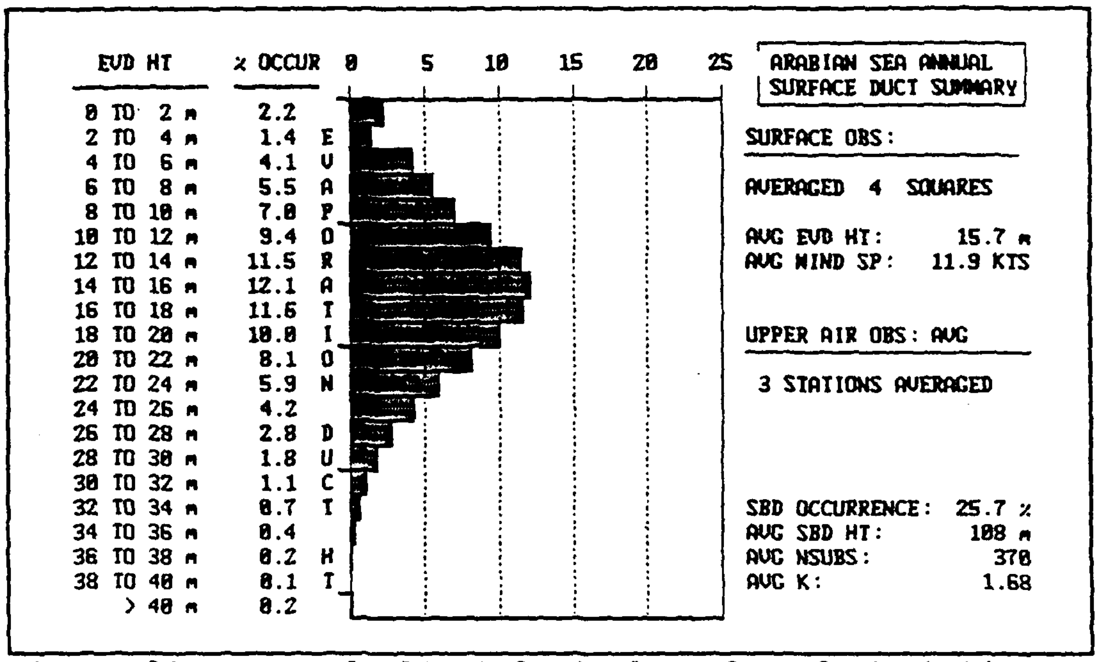


Figure 35 Annual climatological surface duct statistics with evaporation duct histogram for Arabian sea area.

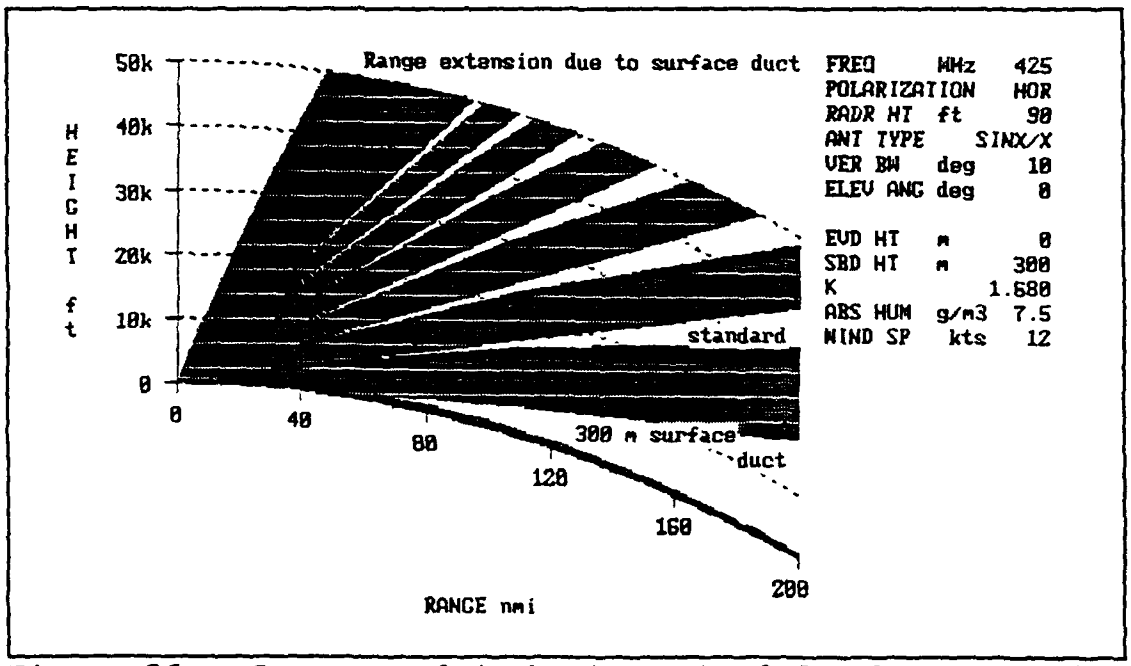


Figure 36 Coverage plot showing extended radar ranges due to a 300 m surface duct.

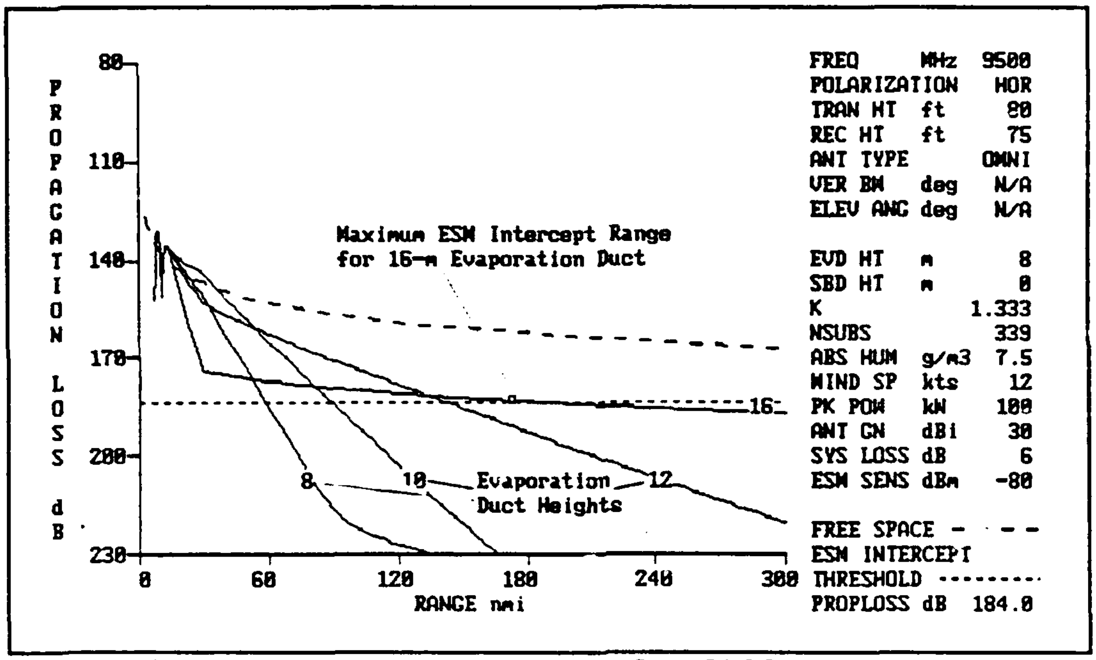


Figure 37 ESM intercept ranges for different evaporation duct heights.

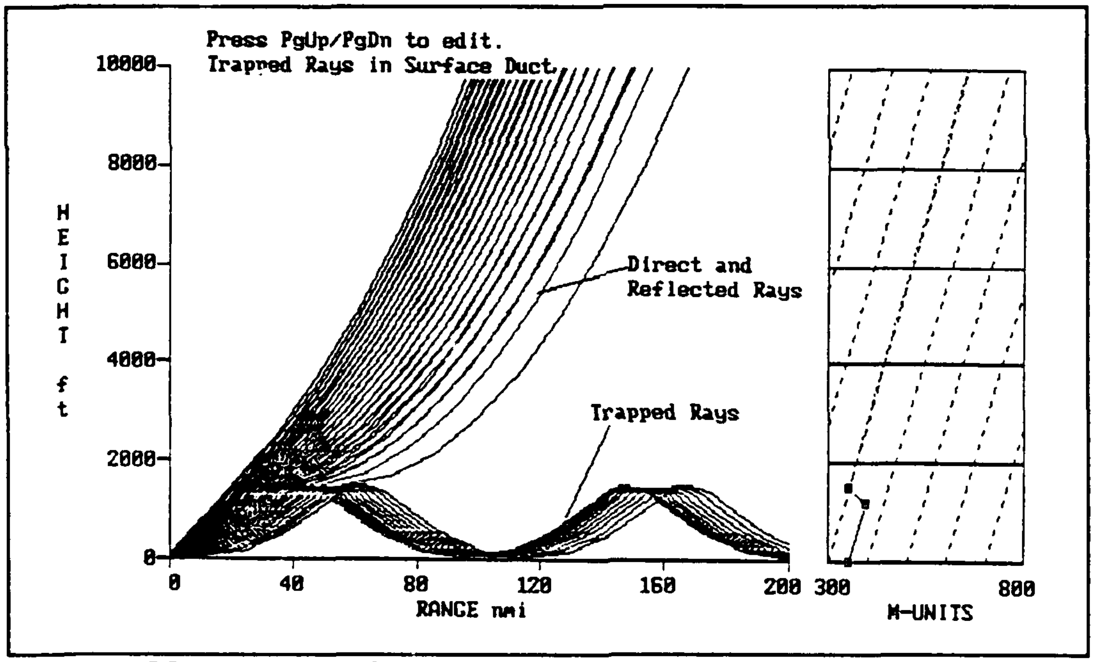


Figure 38 Trapped rays from an antenna at 90 ft in surface duct of 1500 ft with the associated M-profile.

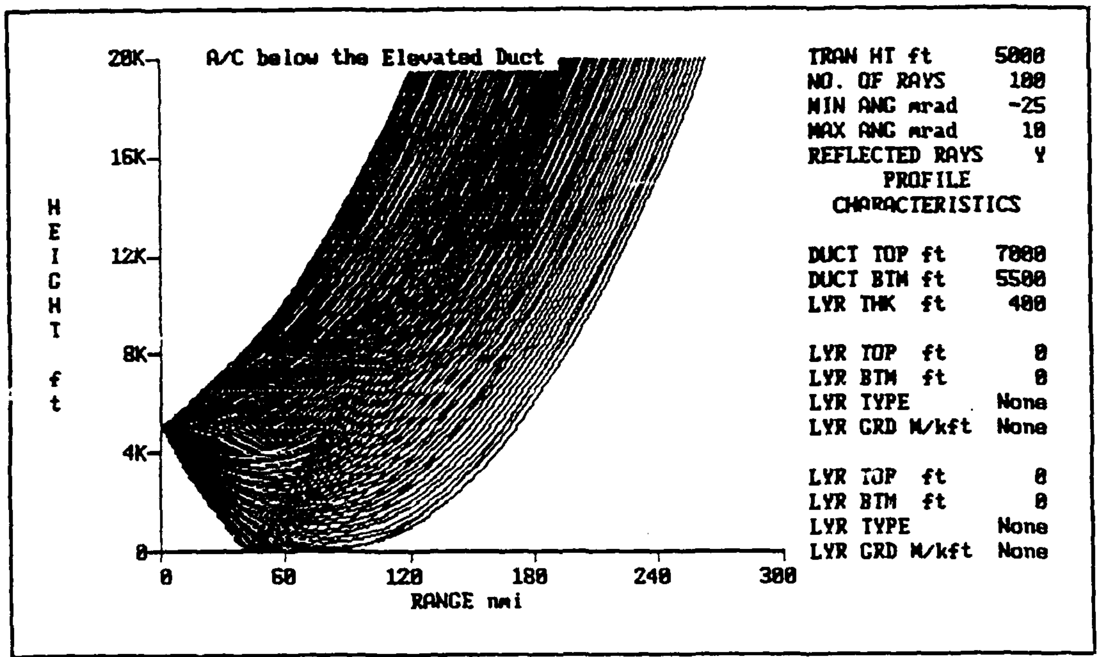


Figure 39 For an elevated duct at 7000 ft, a/c is below the duct. Note no radar holes for a/c below the duct.

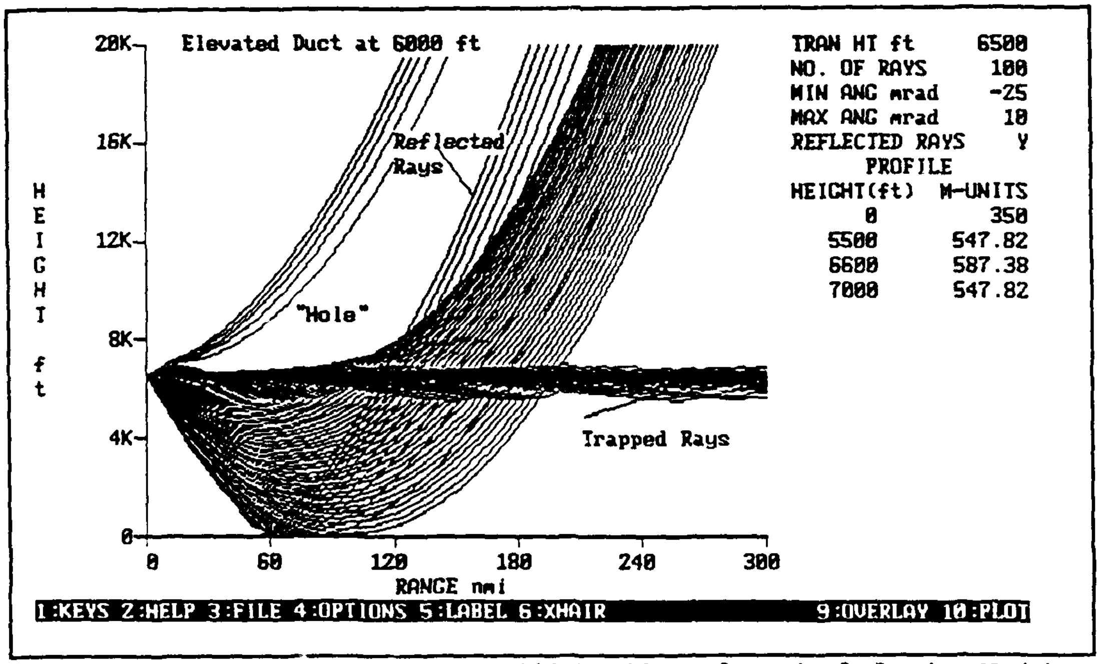


Figure 40 Aircraft now within the elevated duct. Notice the trapped rays in the duct and radar holes.

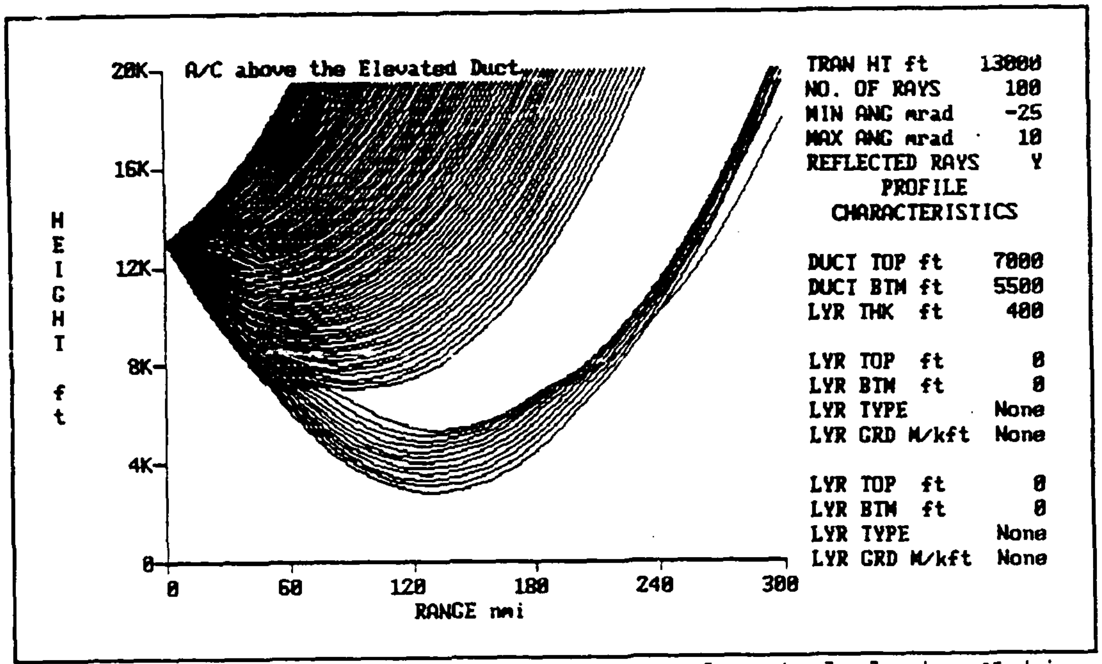


Figure 41 Aicraft is above the elevated duct. Notice radar holes and gaps in radar coverage.

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